# Chapter 2: Costing Methodology for Model Plants

## INTRODUCTION

This chapter presents the methodologies used by the Agency to develop cost estimates at the model plant level for the proposed rule and regulatory options considered. The Agency costs for 539 model plants and these were then used in the economic analysis to scale to the total universe of in-scope facilities. For the model-plant specific projected compliance costs of the proposed rule, see Appendix A of this document. Under the proposed rule, facilities have the option of conducting a cost test against the compliance costs developed by the Agency for support of the regulatory requirements of the rule. The costs presented in Appendix A, and developed based on the methodology presented in this chapter, would form the basis of the "significantly greater" cost test in the proposed rule.

The term model plant is used frequently throughout this document. The Agency notes that model plants are not actual existing facilities. Model Plants are statistical representations of existing facilities (or fractions of existing facilities). Therefore, the cost estimates developed for the rule should not be considered to reflect those exactly of a particular existing facility. However, in the Agency's view, the national estimates of benefits, compliance costs, and economic impacts are representative of those expected from the industry as a whole.

## 2.1 COOLING WATER INTAKE STRUCTURE COSTS

EPA developed distinct sets of intake structure and conduit system costs for existing source model plants expected to (1) upgrade screen systems only, (2) upgrade cooling systems and intake structures, and (3) upgrade cooling systems only.

For those plants projected to incur costs of cooling water intake structure upgrades (but not flow-reducing cooling system conversions), the Agency estimates that intake fanning/expansion would be necessary for the majority of plants projected to install entrainment reducing fine-mesh screens. Therefore, the Agency developed capital costs for these scenarios that incorporate the costs of expanding/fanning or adding an additional bay to an existing intake structure in order to upgrade to fine-mesh screens. Because fine-mesh screens have reduced open cross-sectional area when compared to coarse-mesh screens, the Agency considers the intake expansion/fanning costs to be appropriate in these cases. Even though there is not a set of velocity-based requirements for this proposal, the Agency projects that the model plants expected to upgrade their intake screens from coarse to fine-mesh would reduce their through-screen velocity from the median facility value of 1.5 feet/second to 1.0 feet/second as a result of this technology change. In part, in the Agency's view, the reduced velocity would adopted for the operational requirements of the screens and to balance the impingement reduction benefits of lower velocities with the physical constraints of velocity reduction for existing intake structures. The Agency utilized costs developed for fine-mesh screens with a through-screen velocity of 1.0 feet/second to size the intake for the full design, once-through intake flow. The operation and maintenance (O&M) costs of these screens are calculated based on the same principle. These capital and O&M costs for fine-mesh screens were developed for the New Facility 316(b) rule and are utilized for existing facilities with some modifications. The Agency applies a capital cost construction inflation factor (in addition to a "retrofit" factor discussed in section

2.6) to account for the expansion/fanning of the intake structure, but does not estimate further O&M costs for this one-time activity. Those plants that additionally would install fish handling/return systems to the upgraded screens incur capital and operation and maintenance costs developed based on the size of the larger size screens. See Sections 2.1.1 and 2.1.2 for the development of the cost estimates for capital and O&M costs for fine-mesh screens.

The Agency developed existing facility construction factors (used in addition to "retrofit" factors discussed in Section 2.6) based on the average ratio of intake modification construction costs to costs derived from CWIS equations developed for New Facility projects. Thus the differences reflect differences in construction costs for nuclear and non-nuclear and differences in CWIS installation capital costs. Table 2-1 presents the construction factors for a variety of compliance technologies used as the basis for the costs estimated for this proposal and regulatory options.

**Table 2-1 CWIS Technology Flow Sizing and Construction Factors for Existing Facilities**

| Compliance Cooling System Type | Plant Type | Flow Used to size Cooling Water Intake Technology | Compliance Cooling Water Intake Technology | Construction Factor for Scenario |
|---|---|---|---|---|
| Non-Cooling Tower | Non-nuclear | 100% of Once-through Baseline Design Intake | Fish Handling | None |
| Non-Cooling Tower | Non-nuclear | 100% of Once-through Baseline Design Intake | Fine Mesh Screens | 30%* |
| Non-Cooling Tower | Non-nuclear | 100% of Once-through Baseline Design Intake | Fine Mesh Screens w/ Fish Handling | 15%* |
| Non-Cooling Tower | Nuclear | 100% of Once-through Baseline Design Intake | Fish Handling | None |
| Non-Cooling Tower | Nuclear | 100% of Once-through Baseline Design Intake | Fine Mesh Screens | 65%* |
| Non-Cooling Tower | Nuclear | 100% of Once-through Baseline Design Intake | Fine Mesh Screens w/ Fish Handling | 30%* |

* Existing facility construction factors based on average ratio of intake modification construction costs to costs derived from CWIS equations developed for New Facility projects. Thus the differences reflect differences in construction costs for nuclear and non-nuclear and differences in CWIS installation capital costs.

** For cooling sizing of cooling towers and appropriate flow for determining the costs of retrofitted cooling water systems, see Section 2.2.

Intake modification construction costs are based on the following general framework:

- An increase in screen area of 50% due to conversion from coarse-mesh to fine-mesh.
- Screen size increase will involve demolition of one side of intake and extension in that direction.
- Installation/removal of sheet piling.
- Concrete demolition of one column and one side (cost doubled for nuclear*).

- Excavation (cost doubled for nuclear*).
- Additional concrete foundation.
- Additional concrete side and back wall.
- Additional concrete column.

* EPA doubled costs to account for concerns that use of blasting and high-impact equipment may be limited at nuclear facilities.

Modification construction costs were then increased by the following cost factors:

| Item | Factor |
|---|---|
| Mobilization/Demobilization | 3 % |
| Engineering | 10 % |
| Site Work | 5 % |
| Electrical | 10 % |
| Controls | 3 % |
| Contingency | 10 % |
| Allowance | 5 % |

For those model plants projected to only incur costs of installing fish handling/return systems to existing screens, the Agency developed costs by estimating the size of coarse mesh, 1.5 feet/sec screens. The through-screen velocity of 1.5 feet/sec is the median velocity for all 316b survey respondents. The Agency determined that use of this metric to size the fish handling/return systems was appropriate for the variety of plants projected to incur their capital and operation and maintenance costs as a result of this proposal. The capital cost estimates used here for installation of the fish handling/return systems to existing screens were those developed for new facilities, with an additional inflation (or "retrofit") factor to account for the issues discussed in Section 2.6 below. Section 2.1.1 presents the cost estimates developed for new facilities for fish handling/return systems.

For the those plants projected to incur costs of cooling system conversions and entrainment-reducing fine-mesh screens, the Agency considered the existing intake structures to be of a size too large for a realistic screen retrofit. Therefore, in these cases, the Agency estimated that one-half of the intake bay(s) would be blocked/closed and the retrofitted fine-mesh intake screens would apply to only one-half of the size of the original intake. The Agency considers this a reasonable approach to estimating realistic scenarios where the average plant (as demonstrated in Table 1-12) utilizes multiple intake bays. In the Agency's view, the plant, when presented an equal opportunity option, would utilize the potential cost savings option of installing the fine-mesh screens on only the maximum intake area necessary. For those plants also projected to incur costs of the addition of fish handling/return systems, the Agency estimates the system size based on this concept of closure/blockage of one-half of the existing intake. The operation and maintenance costs are also developed using this size of an intake. Therefore, for the case of each of these retrofit activities, the installed capital costs and operation and maintenance costs of the intake screens and fish handling/return systems are approximately one-half of those for a full size screen replacement.

For those model plants converting their cooling systems from once-through to recirculating systems but not incurring costs of entrainment-reducing intake screens, the existing intake structures are considered to be operational without significant modification (as was the case in the example of the conversions discussed in Chapter 4). In turn, the plants would incur no additional operation and maintenance costs.

The Agency notes that in addition to the intake structure capital costs described above, the capital costs are inflated by the "retrofit" capital cost factor of 30 percent described in section 2.6, below. Therefore, the Agency views the retrofit capital costs developed for upgrading intake screens and structures to be appropriate for existing model plants.

### 2.1.1 Capital and O&M Costs of Intake Structures and Conduit Systems

***Installation of traveling screens with fish baskets for New Facilities***

Single-entry, single-exit vertical traveling screens (conventional traveling screens) contain a series of wire mesh screen panels that are mounted end to end on a band to form a vertical loop. As water flows through the panels, debris and fish that are larger than the screen openings are caught on the screen or at the base of each panel in a basket. As the screen rotates around, each panel in turn reaches a top area where a high-pressure jet spray wash pushes debris and fish from the basket into a trash trough for disposal. As the screen rotates over time, the clean panels move down, back into the water to screen the intake flow.

Conventional traveling screens can be operated continuously or intermittently. However, when these screens are fitted with fish baskets (also called modified conventional traveling screens or Ristroph screens), the screens must be operated continuously so that fish that are collected in the fish baskets can be released to a bypass/return using a low pressure spray wash when the basket reaches the top of the screen. Once the fish have been removed, a high pressure jet spray wash is typically used to remove debris from the screen. In recent years, the design of fish baskets has been refined (e.g., deeper baskets, smoother mesh, better balance) to decrease chances of injury and mortality and to better retain fish (i.e., prevent them from flopping out and potentially being injured). Methods used to protect fish include the Stabilized Integral Marine Protective Lifting Environment (S.I.M.P.L.E.) developed by Brackett Green and the Modified Ristroph design by U.S. Filter.

U.S. Filter's conventional (through flow) traveling screens are typically manufactured in widths ranging from two feet to at least 14 feet, for channel depths of up to 100 feet, although custom design is possible to fit other dimensions.

*Flow*

To calculate the flow through a screen panel, the width of the screen panel is multiplied by the water depth and, using the desired flow velocities (1 foot per second and 0.5 foot per second), is converted to gallons per minute assuming a screen efficiency of 50 percent. The calculated flows for selected screen widths, water depths, and well depths are presented in Tables 2-30 and 2-31. For flows greater than this, a facility would generally install multiple screens or use a custom design.

Well depth includes the height of the structure above the water line. The well depth can be more than the water depth by a few to tens of feet. The flow velocities used are representative of a flow speed that is generally considered to be fish friendly particularly for sensitive species (0.5 fps), and a flow speed that may be more practical for some facilities to achieve but typically provides less fish protection. The water depths and well depths are approximate and may vary based on actual site conditions.

**Table 2-2. Average Flow Through A Traveling Water Screen (gpm) for a Flow Velocity of 1.0 fps**

| Well Depth (ft) | Water Depth (ft) | Basket Panel Screening Width (ft) 2 | 5 | 10 | 14 |
|---|---|---|---|---|---|
| 10 | 8 | 4000 | 9000 | 18,000 | 25,000 |
| 25 | 20 | 9000 | 22,000 | 45,000 | 63,000 |
| 50 | 30 | 13,000 | 34,000 | 67,000 | 94,000 |
| 75 | 50 | 22,000 | 56,000 | 112,000 | 157,000 |
| 100 | 65 | 29,000 | 73,000 | 146,000 | 204,000 |

**Table 2-3. Average Flow Through A Traveling Water Screen (gpm) for a Flow Velocity of 0.5 fps**

| Well Depth (ft) | Water Depth (ft) | Basket Screening Panel Width (ft) 2 | 5 | 10 | 14 |
|---|---|---|---|---|---|
| 10 | 8 | 2000 | 4000 | 9000 | 13,000 |
| 25 | 20 | 4000 | 11,000 | 22,000 | 31,000 |
| 50 | 30 | 7000 | 17,000 | 34,000 | 47,000 |
| 75 | 50 | 11,000 | 28,000 | 56,000 | 79,000 |
| 100 | 65 | 15,000 | 36,000 | 73,000 | 102,000 |

*Capital Costs*

*Equipment Cost*

Basic costs for screens with flows comparable to those shown in the above tables are presented in Tables 2-4 and 2-5. Table 2-4 contains estimated costs for basic traveling screens without fish handling features, that have a carbon steel structure coated with epoxy paint. The costs presented in Table 2-33 are for traveling screens with fish handling features including a spray system, a fish trough, housings and transitions, continuous operating features, a drive unit, frame seals, and engineering. Installation costs and spray pump costs are presented separately below.

**Table 2-4. Estimated Equipment Cost for Traveling Water Screens Without Fish Handling Features[1] (1999 Dollars)**

| Well Depth (ft) | Basket Screening Panel Width (ft) 2 | 5 | 10 | 14 |
|---|---|---|---|---|
| 10 | $30,000 | $35,000 | $45,000 | $65,000 |
| 25 | $35,000 | $45,000 | $60,000 | $105,000 |
| 50 | $55,000 | $70,000 | $105,000 | $145,000 |
| 75 | $75,000 | $100,000 | $130,000 | $175,000 |
| 100 | $115,000 | $130,000 | $155,000 | $200,000 |

1) Cost includes carbon steel structure coated with epoxy paint and non-metallic trash baskets with Type 304 stainless mesh and intermittent operation components.

Source: Vendor estimates.

**Table 2-5. Estimated Equipment Cost for Traveling Water Screens With Fish Handling Features[1] (1999 Dollars)**

| Well depth (ft) | Basket Screening Panel Width (ft) 2 | 5 | 10 | 14 |
|---|---|---|---|---|
| 10 | $63,500 | $73,500 | $94,000 | $135,500 |
| 25 | $81,250 | $97,500 | $133,000 | $214,000 |
| 50 | $122,500 | $152,000 | $218,000 | $319,500 |
| 75 | $163,750 | $210,000 | $283,000 | $414,500 |
| 100 | $225,000 | $267,500 | $348,000 | $504,500 |

1) Cost includes carbon steel screen structure coated with epoxy paint and non-metallic fish handling panels, spray systems, fish trough, housings and transitions, continuous operating features, drive unit, frame seals, and engineering (averaged over 5 units). Costs do *not* include differential control system, installation, and spray wash pumps.

Source: Vendor estimates.

*Installation Cost*

Installation costs of traveling screens for New Facilities are based on the following assumptions of a typical average installation requirement for a hypothetical scenario. Site preparation and earth work are calculated based on the following assumptions:

- ***Clearing and grubbing*:** Clearing light to medium brush up to 4" diameter with a bulldozer.
- ***Earthwork*:** Excavation of heavy soils. Quantity is based on the assumption that earthwork increases with screen width.
- ***Paving and surfacing*:** Using concrete 8" thick and assuming that the cost of pavement attributed to screen installation is 6x3 yards for the smallest screen and 25x6 yards for the largest screen.
- ***Structural concrete*:** The structural concrete work attributed to screen installation is four 12"x12" reinforced concrete columns with depths varying between 1.5 yards and 3 yards. There is more structural concrete work for a water intake structure, however, for new source screens and retrofit screens, only a portion of the intake structural cost can be justifiably attributed to the screen costs. For new screens, most of the concrete structure work is for developing the site to make it accessible for equipment and protect it from hydraulic elements, which are necessary for constructing the intake itself. For retrofits, some of the structural concrete will already exist and some of it will not be needed since the intake is already in place and only the screen needs to be installed. All unit costs used in calculating on-shore site preparation were obtained from *Heavy Construction Cost Data 1998* (R. S. Means, 1997b).

Table 2-6 presents site preparation installation costs that apply to traveling screens both with and without fish handling features. The total onshore construction costs are for a screen to be installed in a 10-foot well depth. Screens to be installed in deeper water are assumed to require additional site preparation work. Hence for costing purposes it is assumed that site preparation costs increase at a rate of an additional 25 percent per depth factor (calculated as the ratio of the well depth to the base well depth of 10 feet) for well depths greater than 10 feet. Table 2-7 presents the estimated costs of site preparation for four sizes of screen widths and various well depths.

**Table 2-6. Estimated Installation (Site Preparation) Costs for Traveling Water Screens Installed at a 10-foot Well Depth (1999 Dollars)**

| Screen Width (ft) | Clearing and Grabbing (acre) | Clearing Cost[1] | Earth Work (cy) | Earth Work Cost[1] | Paving and Surfacing Using Concrete (sy) | Paving Cost[1] | Structural Concrete (cy) | Structural Cost | Total Onshore Construction Costs |
|---|---|---|---|---|---|---|---|---|---|
| 2 | 0.1 | $250 | 200 | $17,400 | 18 | $250 | 0.54 | $680 | $19,000 |
| 5 | 0.35 | $875 | 500 | $43,500 | 40 | $560 | 0.63 | $790 | $46,000 |
| 10 | 0.7 | $1,750 | 1000 | $87,000 | 75 | $1,050 | 0.72 | $900 | $91,000 |
| 14 | 1 | $2,500 | 1400 | $121,800 | 150 | $2,100 | 1.08 | $1,350 | $128,000 |

ft = feet, cy=cubic yard, sy=square yard

1) Clearing cost @ $2,500/acre, earth work cost @ $87/cubic yard, paving cost @ $14/square yard, structural cost @ $1,250/cubic yard.

Source of unit costs: *Heavy Construction Cost Data 1998* (R.S. Means, 1997b).

**Table 2-7. Estimated Installation (Site Preparation, Construction, and Onshore Installation) Costs for Traveling Water Screens of Various Well Depths (1999 Dollars)**

| Well Depth (ft) | Screen Panel Width (ft): 2 | 5 | 10 | 14 |
|---|---|---|---|---|
| 10 | $19,000 | $46,000 | $91,000 | $128,000 |
| 25 | $31,000 | $75,000 | $148,000 | $208,000 |
| 50 | $43,000 | $104,000 | $205,000 | $288,000 |
| 75 | $55,000 | $132,000 | $262,000 | $368,000 |
| 100 | $67,000 | $161,000 | $319,000 | $448,000 |

Source: R.S. Means (1997b) and vendor estimates.

EPA developed a hypothetical scenario of a typical underwater installation to estimate an average cost for underwater installation costs. EPA estimated costs of personnel and equipment per day, as well as mobilization and demobilization. Personnel and equipment costs would increase proportionately based on the number of days of a project, however mobilization and demobilization costs would be relatively constant regardless of the number of days of a project since the cost of transporting personnel and equipment is largely independent of the length of a project. The hypothetical project scenario and estimated costs are presented in Box 2-1. Hypothetical scenario was used to develop installation cost estimates as function of screen width/well depth. Installation costs were then included with total cost equations. To cost facilities, EPA selected appropriate screen width based on flow.

As shown in the hypothetical scenario in Box 2-1, the estimated cost for a one-day installation project would be $8,000 ($4,500 for personnel and equipment, plus $3,500 for mobilization and demobilization). Using this one-day cost estimate as a basis, EPA generated estimated installation costs for various sizes of screens under different scenarios. These costs are presented in Table 2-7. The baseline costs for underwater installation include the costs of a crew of divers and equipment including mobilization and demobilization, divers, a barge, and a crane. The number of days needed is based on a minimum of one day for a screen of less than 5 feet in width and up to 10 feet in well depth. Using best professional judgement (BPJ), EPA estimated the costs for larger jobs assuming an increase of two days for every increase in well depth size and of one day for every increase in screen width size.

**Box 2-1. Example Scenario for Underwater Installation of an Intake Screen System**

This project involves the installation of 12, t-24 passive intake screens onto a manifold inlet system. Site conditions include a 20-foot water depth, zero to one-foot underwater visibility, 60-70 °F water temperature, and fresh water at an inland. The installation is assumed to be 75 yards offshore and requires the use of a barge or vessel with 4-point anchor capability and crane.

*Job Description:*
Position and connect water intake screens to inlet flange via 16 bolt/nut connectors. Lift, lower, and position intake screens via crane anchored to barge or vessel. Between 4 and 6 screens of the smallest size can be installed per day per dive team, depending on favorable environmental conditions.

*Estimated Personnel Costs:*
Each dive team consists of 5 people (1 supervisor, 2 surface tenders, and 2 divers), the assumed minimum number of personnel needed to operate safely and efficiently. The labor rates are based on a 12-hour work day. The day rate for the supervisor is $600. The day rate for each diver is $400. The day rate for each surface tender is $200. Total base day rate per dive team is $1,800.

*Estimated Equipment Costs:*
Use of hydraulic lifts, underwater impact tools, and other support equipment is $450 per day. Shallow water air packs and hoses cost $100 per day. The use of a crane sufficient to lift the 375 lb t-24 intakes is $300 per day. A barge or vessel with 4-point anchor capability can be provided by either a local contractor or the dive company for $1,800 per day (cost generally ranges from $1,500-$2,000 per day). This price includes barge/vessel personnel (captain, crew, etc) but the barge/vessel price does not include any land/waterway transportation needed to move barge/vessel to inland locations. Using land-based crane and dive operations can eliminate the barge/vessel costs. Thus total equipment cost is $2,650 per day.

*Estimated Mobilization and Demobilization Expenses:*
This includes transportation of all personnel and equipment to the job site via means necessary (air, land, sea), all hotels, meals, and ground transportation. An accurate estimate on travel can vary wildly depending on job location and travel mode. For this hypothetical scenario, costs are estimated for transportation with airfare, and boarding and freight and would be $3,500 for the team (costs generally range between $3,000 and $4,000 for a team).

**Table 2-8. Estimated Underwater Installation Costs for Various Screen Widths and Well Depths[1] (1999 Dollars)**

| Well Depth (ft) | Basket Screening Panel Width (ft) 2 | 5 | 10 | 14 |
|---|---|---|---|---|
| 10 | $8,000 | $12,500 | $17,000 | $21,500 |
| 25 | $17,000 | $21,500 | $26,000 | $30,500 |
| 50 | $26,000 | $30,500 | $35,000 | $39,500 |
| 75 | $35,000 | $39,500 | $44,000 | $48,500 |
| 100 | $44,000 | $48,500 | $53,000 | $57,500 |

1) Based on hypothetical scenario of crew and equipment costs of $4,500 per day and mobilization and demobilization costs of $3,500 (see Box 2-1).

Table 2-9 presents total estimated installation costs for traveling screens. Installation costs for traveling screens with fish handling features and those without fish handling features are assumed to be similar.

**Table 2-9. Estimated Total Installation Costs for Traveling Water Screens[1] (1999 Dollars)**

| Well Depth (ft) | Basket Screening Panel Width (ft) 2 | 5 | 10 | 14 |
|---|---|---|---|---|
| 10 | $27,000 | $58,500 | $108,000 | $149,500 |
| 25 | $48,000 | $96,500 | $174,000 | $238,500 |
| 50 | $69,000 | $134,500 | $240,000 | $327,500 |
| 75 | $90,000 | $171,500 | $306,000 | $416,500 |
| 100 | $111,000 | $209,500 | $372,000 | $505,500 |

1) Includes site preparation, and onshore and underwater construction and installation costs.

### *Total Estimated Capital Costs for New Facilities*

The installation costs in Table 2-9 were added to the equipment costs in Tables 2-4 and 2-5 to derive total equipment and installation costs for traveling screens with and without fish handling features. These estimated costs are presented in Tables 2-10 and 2-11. The flow volume corresponding to each screen width and well depth combination varies based on the through screen flow velocity. These flow volumes were presented in Tables 2-12 and 2-13 for flow velocities of 1.0 fps and 0.5 fps, respectively.

**Table 2-10. Estimated Total Capital Costs for Traveling Screens Without Fish Handling Features (Equipment and Installation)[1] (1999 Dollars)**

| Well Depth (ft) | Screening Basket Panel Width (ft) | | | |
|---|---|---|---|---|
| | 2 | 5 | 10 | 14 |
| 10 | $57,000 | $93,500 | $153,000 | $214,500 |
| 25 | $83,000 | $141,500 | $234,000 | $343,500 |
| 50 | $124,000 | $204,500 | $345,000 | $472,500 |
| 75 | $165,000 | $271,500 | $436,000 | $591,500 |
| 100 | $226,000 | $339,500 | $527,000 | $705,500 |

1) Costs include carbon steel structure coated with an epoxy paint, non-metallic trash baskets with Type 304 stainless mesh, and intermittent operation components and installation.

**Table 2-11. Estimated Total Capital Costs for Traveling Screens With Fish Handling Features (Equipment and Installation)[1] (1999 Dollars)**

| Well Depth (ft) | Screening Basket Panel Width (ft) | | | |
|---|---|---|---|---|
| | 2 | 5 | 10 | 14 |
| 10 | $90,500 | $132,000 | $202,000 | $285,000 |
| 25 | $129,250 | $194,000 | $307,000 | $453,000 |
| 50 | $191,500 | $287,000 | $458,000 | $647,000 |
| 75 | $253,750 | $381,500 | $589,000 | $831,000 |
| 100 | $336,000 | $477,000 | $720,000 | $1,010,000 |

1) Costs include non-metallic fish handling panels, spray systems, fish trough, housings and transitions, continuous operating features, drive unit, frame seals, engineering (averaged over 5 units), and installation. Costs do *not* include differential control system and spray wash pumps.

Tables 2-12 and 2-13 present equations that can be used to estimate costs for traveling screens at 0.5 fps and 1.0 fps, respectively. See the Appendix B for cost curves and equations.

**Table 2-12. Capital Cost Equations for Traveling Screens for Velocity of 0.5 fps**

| Screen Width (ft) | Traveling Screens with Fish Handling Equipment: Equation[1] | Correlation Coefficient | Traveling Screens without Fish Handling Equipment: Equation[1] | Correlation Coefficient |
|---|---|---|---|---|
| 2 | $y = 6E\text{-}08x^3 - 0.0014x^2 + 28.994x + 36372$ | $R^2 = 0.9992$ | $y = 5E\text{-}08x^3 - 0.0013x^2 + 20.892x + 18772$ | $R^2 = 0.9991$ |
| 5 | $y = 1E\text{-}09x^3 - 8E\text{-}05x^2 + 12.223x + 80790$ | $R^2 = 0.994$ | $y = 2E\text{-}09x^3 - 0.0001x^2 + 9.7773x + 54004$ | $R^2 = 0.9995$ |
| 10 | $y = 5E\text{-}10x^3 - 9E\text{-}05x^2 + 12.726x + 88302$ | $R^2 = 0.9931$ | $y = 5E\text{-}03x^3 - 9E\text{-}05x^2 + 10.143x + 63746$ | $R^2 = 0.9928$ |
| 14 | $y = 6E\text{-}10x^3 - 0.0001x^2 + 15.874x + 91207$ | $R^2 = 0.995$ | $y = 5E\text{-}10x^3 - 0.0001x^2 + 12.467x + 65934$ | $R^2 = 0.9961$ |

1) x is the flow in gpm y is the capital cost in dollars.

**Table 2-13. Capital Cost Equations for Traveling Screens for Velocity of 1 fps**

| Screen Width (ft) | Traveling Screens with Fish Handling Equipment: Equation[1] | Correlation Coefficient | Traveling Screens without Fish Handling Equipment: Equation[1] | Correlation Coefficient |
|---|---|---|---|---|
| 2 | $y = 8E\text{-}09x^3 - 0.0004x^2 + 15.03x + 33044$ | $R^2 = 0.9909$ | $y = 8E\text{-}09x^3 - 0.0004x^2 + 10.917x + 16321$ | $R^2 = 0.9911$ |
| 5 | $y = 2E\text{-}10x^3 - 3E\text{-}05x^2 + 6.921x + 68688$ | $R^2 = 0.9948$ | $y = 3E\text{-}10x^3 - 4E\text{-}05x^2 + 5.481x + 44997$ | $R^2 = 0.9962$ |
| 10 | $y = 5E\text{-}11x^3 - 2E\text{-}05x^2 + 6.2849x + 88783$ | $R^2 = 0.9906$ | $y = 5E\text{-}11x^3 - 2E\text{-}05x^2 + 5.0073x + 64193$ | $R^2 = 0.9902$ |
| 14 | $y = 5E\text{-}11x^3 - 2E\text{-}05x^2 + 7.1477x + 113116$ | $R^2 = 0.9942$ | $y = 5E\text{-}11x^3 - 2E\text{-}05x^2 + 5.6762x + 81695$ | $R^2 = 0.9952$ |

1) x is the flow in gpm y is the capital cost in dollars.

*Operation and Maintenance (O&M) Costs for Traveling Screens*

O&M costs for traveling screens vary by type, size, and mode of operation of the screen. Based on discussions with industry representatives, EPA estimated annual O&M cost as a percentage of total capital cost. The O&M cost factor ranges between 8 percent of total capital cost for the smallest size traveling screens with and without fish handling equipment and 5 percent for the largest traveling screen since O&M costs do not increase proportionately with screen size. Estimated annual O&M costs for traveling screens with and without fish handling features are presented in Tables 2-4 and 2-5, respectively. As noted earlier, the flow volume corresponding to each screen width and well depth combination varies based on the through screen flow velocity. These flow volumes were presented in Tables 2-14 and 2-15 for flow velocities of 1.0 fps and 0.5 fps, respectively.

**Table 2-14. Estimated Annual O&M Costs for Traveling Water Screens Without Fish Handling Features (Carbon Steel - Standard Design)[1] (1999 Dollars)**

| Well Depth (ft) | Screen Panel Width (ft): 2 | 5 | 10 | 14 |
|---|---|---|---|---|
| 10 | $4560 | $6545 | $7650 | $12,870 |
| 25 | $5810 | $9905 | $14,040 | $17,175 |
| 50 | $8680 | $12,270 | $17,250 | $23,625 |
| 75 | $11,550 | $16,290 | $21,800 | $29,575 |
| 100 | $13,560 | $16,975 | $26,350 | $35,275 |

1) Annual O&M costs range between 8 percent of total capital cost for the smallest size traveling screens with and without fish handling equipment and 5 percent for the largest traveling screen.

**Table 2-15. Estimated Annual O&M Costs for Traveling Water Screens With Fish Handling Features (Carbon Steel Structure, Non-Metallic Fish Handling Screening Panel)[1] (1999 Dollars)**

| Well Depth (ft) | Screen Panel Width (ft) 2 | 5 | 10 | 14 |
|---|---|---|---|---|
| 10 | $7240 | $9240 | $10,100 | $17,100 |
| 25 | $9048 | $13,580 | $18,420 | $22,650 |
| 50 | $13,405 | $17,220 | $22,900 | $32,350 |
| 75 | $17,763 | $22,890 | $29,450 | $41,550 |
| 100 | $20,160 | $23,850 | $36,000 | $50,500 |

1) Annual O&M costs range between 8 percent of total capital cost for the smallest size traveling screens with and without fish handling equipment and 5 percent for the largest traveling screen.

The tables below present O&M cost equations generated from the above tables for various screen sizes and water depths at velocities of 0.5 fps and 1 fps, respectively. The "x" value of the equation is the flow and the "y" value is the O&M cost in dollars.

**Table 2-16: Annual O&M Cost Equations for Traveling Screens Velocity 0.5 fps**

| Screen Width (ft) | Traveling Screens with Fish Handling Equipment: Equation[1] | Correlation Coefficient | Traveling Screens without Fish Handling Equipment: Equation[1] | Correlation Coefficient |
|---|---|---|---|---|
| 2 | $y = -3E\text{-}05x^2 + 1.6179x + 3739.1$ | $R^2 = 0.9943$ | $y = -2E\text{-}05x^2 + 1.0121x + 2392.4$ | $R^2 = 0.9965$ |
| 5 | $y = -1E\text{-}05x^2 + 0.8563x + 5686.3$ | $R^2 = 0.9943$ | $y = -7E\text{-}06x^2 + 0.6204x + 4045.7$ | $R^2 = 0.9956$ |
| 10 | $y = -2E\text{-}06x^2 + 0.5703x + 5864.4$ | $R^2 = 0.9907$ | $y = 9E\text{-}11x^3 - 1E\text{-}05x^2 + 0.8216x + 1319.5$ | $R^2 = 0.9997$ |
| 14 | $y = 5E\text{-}12x^3 - 1E\text{-}06x^2 + 0.4835x + 10593$ | $R^2 = 0.9912$ | $y = 8E\text{-}12x^3 - 2E\text{-}06x^2 + 0.3899x + 7836.7$ | $R^2 = 0.9922$ |

1) x is the flow in gpm and y is the annual O&M cost in dollars.

| Table 2-17. Annual O&M Cost Equations for Traveling Screens Velocity 1 fps | | | | |
|---|---|---|---|---|
| | Traveling Screens with Fish Handling Equipment | | Traveling Screens without Fish Handling Equipment | |
| Screen Width (ft) | Equation[1] | Correlation Coefficient | Equation[1] | Correlation Coefficient |
| 2 | $y = -8E\text{-}06x^2 + 0.806x + 3646.7$ | $R^2 = 0.982$ | $y = -4E\text{-}06x^2 + 0.5035x + 2334$ | $R^2 = 0.9853$ |
| 5 | $y = -3E\text{-}06x^2 + 0.4585x + 5080.7$ | $R^2 = 0.9954$ | $y = -2E\text{-}06x^2 + 0.3312x + 3621.1$ | $R^2 = 0.9963$ |
| 10 | $y = -6E\text{-}07x^2 + 0.2895x + 5705.3$ | $R^2 = 0.9915$ | $y = 1E\text{-}11x^3 - 3E\text{-}06x^2 + 0.4047x + 1359.4$ | $R^2 = 1$ |
| 14 | $y = -3E\text{-}13x^3 - 4E\text{-}08x^2 + 0.2081x + 11485$ | $R^2 = 0.9903$ | $y = 4E\text{-}13x^3 - 3E\text{-}07x^2 + 0.1715x + 8472.1$ | $R^2 = 0.9913$ |

1) x is the flow in gpm and y is the annual O&M cost in dollars.

***Adding fish baskets to existing traveling screens***

*Capital Costs*

Table 2-17 presents estimated costs of fish handling equipment without installation costs. These estimated costs represent the difference between costs for equipment with fish handling features (Table 2-33) and costs for equipment without fish handling features (Table 2-4), plus a 20 percent add-on for upgrading existing equipment (mainly to convert traveling screens from intermittent operation to continuous operation).[1] These costs would be used to estimate equipment capital costs for upgrading an existing traveling water screen to add fish protection and fish return equipment.

| Table 2-18. Estimated Capital Costs of Fish Handling Equipment (1999 Dollars) | | | | |
|---|---|---|---|---|
| | Basket Screening Panel Width (ft) | | | |
| Well Depth (ft) | 2 | 5 | 10 | 14 |
| 10 | $40,200 | $46,200 | $58,800 | $84,600 |
| 25 | $55,500 | $63,000 | $87,600 | $131,400 |
| 50 | $81,000 | $99,000 | $135,600 | $209,400 |
| 75 | $106,500 | $132,000 | $183,600 | $287,400 |
| 100 | $132,000 | $165,000 | $231,600 | $365,400 |

Source: Vendor estimates.

[1]This 20 percent additional cost for upgrades to existing equipment was included based on recommendations from one of the equipment vendors supplying cost data for this research effort.

*Installation of Fish Handling Features to Existing Traveling Screens*

As stated earlier, the basic equipment cost of fish handling features (presented in Table 2-18) is calculated based on the difference in cost between screens with and without fish handling equipment, plus a cost factor of 20 percent for upgrading the existing system from intermittent to continuous operation. Although retrofitting existing screens with fish handling equipment will require upgrading some mechanical equipment, installing fish handling equipment generally will not require the use of a costly barge that is equipped with a crane and requires a minimum number of crew to operate it. EPA assumed that costs are 75 percent of the underwater installation cost (Table 2-8) for a traveling screen (based on BPJ). Table 2-19 shows total estimated costs (equipment and installation) for adding fish handling equipment to an existing traveling screen.

**Table 2-19. Estimated Capital Costs of Fish Handling Equipment and Installation[1] (1999 Dollars)**

| Well Depth (ft) | Basket Screening Panel Width (ft) 2 | 5 | 10 | 14 |
|---|---|---|---|---|
| 10 | $46,200 | $55,575 | $71,550 | $100,725 |
| 25 | $68,250 | $79,125 | $107,100 | $154,275 |
| 50 | $100,500 | $121,875 | $161,850 | $239,025 |
| 75 | $132,750 | $161,625 | $216,600 | $323,775 |
| 100 | $165,000 | $201,375 | $271,350 | $408,525 |

1) Installation portion of the costs estimated as 75 percent of the *underwater* installation cost for installing a traveling water screen.

The additional O&M costs due to the installation of fish baskets on existing traveling screens can be calculated by subtracting the O&M costs for basic traveling screens from the O&M costs for traveling screens with fish baskets. See the Appendix B for cost curves and equations.

*Other CWIS Technologies*

Fine mesh traveling screens and traveling screens with fish handling are but two means by which facilities may comply with the impingement and/or entrainment reduction requirements of the proposed rule. The Agency based its cost estimates on the technologies outlined here, in part due to their prevalence, their applicability to the primary types of intake structures at existing facilities within the scope of the rule, and for their conservative costs (that is, fine mesh traveling screens tend to have higher costs, in the Agencies estimation than other similar technologies). As such, the Agency notes that there are many ways by which facilities may comply with the requirements of this rule and that the costs will be comparable to those developed here and presented in Appendix A. In that regard, the Agency has prepared cost estimates for other comparable screening systems to those presented here and gave the majority of this information in the Technical Development Document for the Final Regulations Addressing Cooling Water Intake Structures for New Facilities (EPA-821-R-01-036), hereinafter referred to as the New Facility TDD. The Agency refers the reader to the New Facility TDD for information on the development of cost for other technologies that facilities may consider for meeting the proposed impingement and entrainment requirements. In addition, Appendix B of this document contains additional cost curves for technologies the Agency analyzed for the development of this rule and the New Facility rule. In addition, Chapter 3 presents a detailed analysis of the types and performance of technologies that facilities may use to comply with the proposed existing facility rule.

## 2.2 Outline of Cooling System Conversion Costing Methodology

Under certain regulatory options considered (those described in Chapter 4.3), existing facilities are projected to install recirculating wet cooling systems. The Agency developed a methodology for estimating the costs of converting model-facility cooling systems from once-through to recirculating operation in the effort of reproducing the costs and engineering characteristics of the example cooling system conversion cases presented in Chapter 4. The methodology for estimating costs of these cooling system conversions is based on the principles observed in the empirical cases and in historical proposals for cooling system conversions (see Chapter 4 for more discussion). The commonalities and/or principles are as follows:

- recirculating systems can be connected to the existing condensers and operated successfully under a variety of conditions (but not all);
- condenser flows generally do not change due to the conversions;
- significant portions of the condenser conduit systems can be used for the recirculating tower systems;
- existing cooling water pumps generally would be replaced with new circulating water pumps or booster pumps would be installed to increase pumping energy of the circulating system;
- the existing intake structures can be used for supplying make-up water to the recirculating towers (though demolition and replacement of the intake pumps may be necessary);
- pumping distances from tower systems to condensers can be significant, but existing piping runs can, in some cases, be utilized to reduce the amount of new circulating piping installed;
- tower structures can be constructed on-site before connection to the existing conduit system; and
- modification and branching of circulating piping is necessary for connecting the recirculating system to the existing conduits and for providing make-up water to the towers.

Based on these principles, the Agency developed cost estimates for cooling system conversions utilizing those developed for new, “greenfield” facilities and inflated these costs by a “retrofit” factor to account for activities outside the scope of the “greenfield” cost estimates. See sections 2.1 and 2.2 for the cost estimates for “greenfield” cooling tower systems and intake structures. See section 2.6 for a discussion of the “retrofit” factor.

*Condenser Refurbishments for Cooling System Conversions*

The Agency includes costs for condenser refurbishments at a subset of facilities expected to comply with flow reduction requirements in the regulatory options considered. The Agency projects premature condenser refurbishments, in part, to alleviate potential condenser tube failures, such as that experienced at the Palisades plant. The Agency researched the materials of construction of surface condensers for the model plants under certain regulatory options and for the example cases described in Chapter 4. The Agency also consulted with condenser manufacturing representatives for advice on probable causes for condenser failures due to cooling system conversions, motivations for condenser replacements or refurbishments, useful lives of condensers, and appropriate tube materials for recirculating cooling systems for a variety of water types. Of the four example cases in Chapter 4, only the Palisades plant experienced condenser failure potentially related to the cooling system conversion. Plant personnel were not able to confirm the condenser tube material at the time of the failure, nor were they able to positively confirm the cause of the failure as relating to the recirculating system. Hence, the Agency could not isolate the specific cause of the Palisades failure and, therefore, relied on additional information to determine which plants would likely replace condensers in order to upgrade the cooling system under certain regulatory options. The Agency learned from condenser vendors that plants would elect to upgrade condenser tube materials to increase the efficiency of the recirculating cooling system. In addition, based on the circumstantial evidence that the Palisades failure happened, at least in part, due to the chemical addition necessary for the recirculating system and the fact that many of the plants projected to upgrade their cooling systems under certain regulatory options utilize brackish or saline cooling water, the Agency judged that the material of the tubes would need to withstand corrosive effects of chemical addition and increased salt content of the cooling water (due to concentration in a recirculating system). Hence, the Agency concluded that meeting a baseline standard of condenser tube material would determine which model plants would most likely upgrade condenser tube materials. See section 3.2.4 for further information on condenser refurbishments.

*Condenser Flows for Cooling System Conversions*

Based on the example cases of cooling system conversions in Chapter 4, the Agency determined that condenser flows would not change as a result of cooling system upgrades. The cooling water flow through these tube bundles would be the same as for the once-through systems due to the fact that each of the example cases utilized the original, once-through designed, cooling water flow. In addition to the empirical example cases, the Agency researched condenser flow to MW ratios to determine if cooling system type influenced the flow rate to capacity ratio. Published condenser flows and generating capacity data from the Nuclear Regulatory Commission (DCN 4-2521)) for all nuclear units in the US demonstrates that recirculating cooling systems have lower condenser flow to MW ratios than once-through systems, regardless of age or other characteristics. After considering this information, EPA chose a conservative approach and used the design cooling water intake flow of the baseline once-through system intake to estimate the size of the recirculating cooling tower and associated conduit system for its model facilities. EPA notes that design flows are significantly higher than operating flows in some cases. As such, the approach of the Agency is additionally conservative, in that facilities considering cooling system conversions could optimize the design of the circulating flow levels appropriate for the facilities operating flows if sufficient unused design intake capacity exists.

*Reuse of Existing Intake Structures for Supplying Make-up Water to Cooling Towers*

As demonstrated by the example cases in Chapter 4, conversions from once-through to recirculating cooling systems do not require construction of new intake structures to provide make-up water to the cooling tower systems. Installation of a fully recirculating cooling system reduces intake flow by upwards of approximately 92 percent as compared to a once-through system. In turn the intake structure designed for a once-through cooling system is oversized for moving flows reduced to this level. For the case of the Palisades plant, the original intake structure withdrew water from a submerged offshore intake. The plant continued to utilize this intake structure (a velocity cap) and the associated submerged piping system (3300 ft) after the conversion. A branch from the onshore portion of the original intake conduit system provided make-up flow to the cooling tower via a separate pump system. The Agency includes capital costs for the conduit system required to bring make-up water to the cooling tower and basin. See Example 1 of this chapter for a discussion of the makeup and blowdown piping associated with the Agency's cooling system conversion estimates. The Agency includes these costs to account for conversion cases in which significant distances may exist between intake locations and cooling tower sites. The Agency notes, as described in Example 1, that these piping capital costs are further inflated by the "retrofit" factor to account for construction techniques and situations outside the scope of a typical "greenfield" cost estimate. In turn, the Agency views the inclusion of these cost estimates as conservative and appropriate for cooling system conversions.

*Cooling Tower Construction and Conduit Connections*

The actual process of adjoining the cooling tower system to the existing condenser conduit system is reported to have not disrupted service significantly for two of the example cases presented in Chapter 4. However, for the Palisades plant, Consumers Energy report that the outage lasted approximately 10 months for connection and start-up of the cooling tower system (see Chapter 4). The Agency estimates for the flow-reduction regulatory options considered that the typical process of adjoining the recirculating system to the existing condenser unit and the refurbishment of the existing condenser (when necessary) would last approximately two months. Because the Agency analyzed flexible compliance dates (extended over a five-year compliance period), the Agency estimated that plants under the flow-reduction regulatory options could plan the cooling system conversion to coincide with periodic scheduled outages, as was the case for the example cases. For the case of nuclear units, these outages can coincide with periodic inspections (ISIs) and refueling. For the case of fossil-fuel and combined-cycle units, the conversion can be planned to coincide with periodic maintenance. Even though ISIs for nuclear units last typically 2 to 4 months, which would extend equal to or beyond the time required to connect the converted system, the Agency estimates for all model plants one month of interrupted service due to the cooling system conversion. For further information see Chapter 4 of this document and the EBA.

Connections of circulating systems to existing once-through conduits, in the Agency's view, would occur through either demolition and/or removal of the connecting piping and/or through branching (and plugging) of the existing conduit system outside the condenser buildings. The Agency estimates that the primary activities fall within the scope of types of construction projects accounted for by the "retrofit" capital cost inflation factor (see Section 2.6 below). Note that the Agency applies the "retrofit" factor to each capital cost outlay for the entire project. Therefore, the branching/connection of the cooling system conduit system could be accounted for in the inflation of a variety of cost components.

### 2.2.1 Capital Costs of Wet Towers

As described in section 2.2, above, in order to develop cooling system conversion costs for existing facilities, the Agency modified the capital cost estimates for wet cooling tower systems that it developed for new, "greenfield" facilities in the 316b Phase I Rule for New Facilities by applying a "retrofit" factor. The description of the Agency's cost estimates for cooling tower systems at new facilities is presented below:

For cooling towers, EPA developed cost estimates for use at a range of different total recirculating flow volumes. The cost for flow reduction technologies depends on many factors, including site-specific conditions. The Agency determined that the factor that is most relevant is the total flow. Therefore, EPA selected total flow as the factor on which to base unit costs and thus use for basic cost comparisons.

The maximum cooling flow value used to develop the wet tower cost equations (both Capital and O&M) was 204,000 gpm. If the model facility flow value exceeded this maximum by 10 percent (i.e., > 225,000 gpm), EPA costed multiple parallel wet tower units.

Recirculating the cooling water in a system vastly reduces the amount of cooling water needed. The method most frequently used to cool the water in a recirculating system is putting the cooling water through a cooling tower. Therefore, EPA chose to cost cooling towers as the technology used to switch a once-through cooling system to a recirculating system.

The factors that generally have the greatest impact on cost are the flow, approach (the difference between cold water temperature and ambient wet bulb temperature), tower type, and environmental considerations. Physical site conditions (e.g., topographic conditions, soils and underground conditions, water quality) affect cost, but in most situations are secondary to the primary cost factors. Relative capital and operation cost estimates for various types of cooling towers are estimated in literature (Mirsky et al. (1992), Mirsky and Bauthier (1997), and Mirsky (2000))[2].

Other characteristics of cooling towers include:

- *Air flow*: Mechanical draft towers use fans to induce air flow, while natural draft (i.e., hyperbolic) towers induce natural air flow by the chimney effect produced by the height and shape of the tower. For towers of similar capacity, natural draft towers typically require significantly less land area and have lower power costs (i.e., fans to induce air flow are not needed) but have higher initial costs (particularly because they need to be taller) than mechanical draft towers. Both mechanical draft and natural draft towers can be designed for air to flow through the fill material using either a crossflow (air flows horizontally) or counterflow (air flows vertically upward) design, while the water flows vertically downward. Counterflow towers tend to be more efficient at achieving heat reduction but are generally more expensive to build and operate because clearance needed at the bottom of the tower means the tower needs to be taller.

- *Mode of operation*: Cooling towers can be either recirculating (water is returned to the condenser for reuse) or non-recirculating (tower effluent is discharged to a receiving waterbody and not reused). Facilities using non-recirculating types (i.e., "helper" towers) draw large flows for cooling and therefore do not provide fish protection for §316(b) purposes, so the information in this chapter is not intended to address non-recirculating towers.

- *Construction materials*: Towers can be made from concrete, steel, wood, and/or fiberglass.

*Capital Cost of Cooling Towers (New Facility Cost Development)*

The volume of water needed for cooling depends on the following critical parameters: water temperature, make of equipment to be used (e.g, G.E turbine vs. ABB turbine, turbine with heat recovery system and turbine without heat recovery system), discharge permit limits, water quality (particularly for wet cooling towers), and type of wet cooling tower (i.e., whether it is a natural draft or a mechanical draft).

Two cooling tower industry managers with extensive experience in selling and installing cooling towers to power plants and other industries provided information on how they estimate budget capital costs associated with a wet cooling tower. The rule of thumb they use is $30/gpm for an approach of 10 degrees and $50/gpm for an approach of 5 degrees.[3] This

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[2] In developing cost estimates for hybrid-wet/dry cooling towers included in Charts 2-1 through 2-6 of the attachments to this chapter, the Agency computed the capital costs of the hybrid tower unit according to the factors referenced here. The Agency then applied an inflation factor to account for the auxiliary components of installation of a cooling tower system. However, this may overstate the costs of hybrid towers in comparison to wet (only) systems, for the fact that hybrid and wet (only) towers would have roughly identical installation costs (see Appendix C of this document for a discussion of the installation costs of hybrid towers and Chapter 6 for a discussion of the relative costs of plume abatement (that is, hybrid towers) versus wet (only) cooling towers).

[3] The approach is the difference between the cold water (tower effluent) temperature and the tower wet bulb temperature. This is also referred to as the design approach. For example, at design conditions with

cost is for a "small" tower (flow less than 10,000 gpm) and equipment associated with the "basic" tower, and does not include installation. Important auxiliary costs are included in the installation factor estimate listed below. Above 10,000 gpm, to account for economy of scale, the unit cost was lowered by $5/gpm over the flow range up to 204,000 gpm. For flows greater than 204,000 gpm, a facility may need to use multiple towers or a custom design. Combining this with the variability in cost among various cooling tower types, costs for various tower types and features were calculated for the flows used.

To estimate costs specifically for installing and operating a particular cooling tower, important factors include:

- *Condenser heat load and wet bulb temperature (or approach to wet bulb temperature)*: Largely determine the size needed. Size is also affected by climate conditions.

- *Plant fuel type and age/efficiency*: Condenser discharge heat load per Megawatt varies greatly by plant type (nuclear thermal efficiency is about 33 percent to 35 percent, while newer oil-fired plants can have nearly 40 percent thermal efficiency, and newer coal-fired plants can have nearly 38 percent thermal efficiency).[4] Older plants typically have lower thermal efficiency than new plants.

- *Topography*: May affect tower height and/or shape, and may increase construction costs due to subsurface conditions. For example, sites requiring significant blasting, use of piles, or a remote tower location will typically have greater installation/construction cost.

- *Material used for tower construction*: Wood towers tend to be the least expensive, followed by fiberglass reinforced plastic, steel, and concrete. However, some industry sources claim that Redwood capital costs might be much higher compared to other wood cooling towers, particularly in the Northwest U.S., because Redwood trees are a protected species. Factors that affect the material used include chemical and mineral composition of the cooling water, cost, aesthetics, and local/regional availability of materials.

Capital costs for the recirculating wet tower include costs for all installation components, such as site preparation and clearing, support foundation, electrical wiring and controls, basin and sump, cicrulating piping, blowdown water treatment system, and recirculating pump and housing costs. Wet tower costs are based on cost data for redwood towers with splash fill and an approach of 10 $^{o}$F taken from Chart 2-3 in the attachments to this chapter. This tower equation does not include make-up and blowdown piping, intake pumps, intake structure and screening technologies.

In order to account for the important auxiliary costs of installing the cooling tower system, the Agency obtained estimates from industry representatives for installation costs as an inflation percentage of the installed cooling tower unit costs. The factor that EPA obtained is 80 percent, which experienced industry representatives described as the average installation inflation factor. The Agency used this factor to inflate the rule of thumb described above for 10

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a delta or design approach of 5 degrees, the tower effluent and blowdown would be 5 degrees warmer than the wet bulb temperature. A smaller delta (or lower tower effluent temperature) requires a larger cooling tower and thus is more expensive.

[4] With a 33 percent efficiency, one-third of the heat is converted to electric energy and two-thirds goes to waste heat in the cooling water.

degree F approach towers (from approximately $30 / gpm to $54 / gpm for the total project cost of a small douglas fir tower and from $25 / gpm to $ 45 / gpm for large fir towers). The Agency chose the median design approach of 10 degrees F based on empirical data from recently installed cooling towers at a variety of geographic locations and plant sizes (See Attachment C to Chapter 5). Applying the factors provided in literature for converting from douglas fir material to other types of cooling towers, the Agency derived capital cost equations for basic cooling towers of douglas fir, redwood, concrete, steel, and fiberglass reinforced plastic. For example, using the Agency's methodology for new facilities, the installed cost of a basic 205,000 gpm fiberglass tower would be expressed as follows: $25 * 1.8 * 110 / 100 * 205,000 = $10,147,500 (in 1999 $). To accommodate the relatively standard application of splash fill the Agency additionally multiplied by the factor for splash fill from the literature tower factors. For example, using the new facility methodology for the installation of a 205,000 gpm redwood tower with splash fill would be expressed as follows: $25 * 1.8 * 120 / 100 * 112 / 100 * 205,000 = $12,398,400 (in 1999 $). The Agency developed a series of these calculations for each type of tower using the literature factors and fitted curves to the results. These curve fits are presented in Appendix B of this document as Figures 2-1 through 2-6. The Agency determined that the median cost material was redwood, which is just slightly more expensive than fiberglass reinforced plastic. The Agency learned from cooling tower vendors that fiberglass has become relatively standard for new facility installations, and therefore chose to use the median costs of the redwood because they slightly exceeded those of fiberglass. As such, the Agency primarily developed installed cooling tower costs for the new facility rule using the equation for redwood towers with splash fill. The equation for an installed redwood mechanical-draft cooling tower unit with 10 degree F design approach and splash fill is as follows:

y = -5E-5 x^2 + 70.721 x + 25393 , (in 1999 $)
where x = flow in gallons per minute, valid up to 225,000 gpm.

For existing facility estimates of cooling tower conversions at non-nuclear facilities, this equation is the starting point for assessing the conversion project costs. In addition to the retrofit factor described in Section 2.6 below, the Agency also added additional makeup and discharge piping capital costs according to the methodology presented in Example 2, which demonstrates how the Agency estimated cooling tower conversion costs for certain regulatory options considered for this proposal.

Similarly, the Agency developed the following equation for the installation capital costs of mechanical-draft concrete cooling tower systems with splash fill:

y = -6E-5 x^2 + 87.845 x + 31674 , (in 1999 $)
where x = flow in gallons per minute, valid up to 225,000 gpm.

This equation was used as the starting point for assessing cooling tower conversion project capital costs for nuclear facilities for certain regulatory options of this proposed rule. See Example 2 for a demonstration of the incorporation of regional cost factors, the retrofit factor, and makeup and discharge piping costs with the above capital cost equation.

EPA obtained data for 20 cooling tower construction projects: nine Douglas fir towers, eight fiberglass towers, one redwood tower, and two towers for which the construction material was unknown (for purposes of comparison, EPA compared these last two towers to predicted costs for redwood towers). In some cases, the project costs did not include certain components such as pumps or basins. Where this was the case, EPA adjusted the project costs as follows:

- where project costs did not include pumps, EPA added $10/gpm to the project costs to account for pumps.
- where project costs did not include pumps and basins, EPA doubled the project costs to account for pumps and basins.

Chart 2-7 in the attachments to this chapter compares actual, total capital costs for wet cooling tower projects against predicted costs from EPA's cooling tower capital cost curves, with 25 percent error bars around the cost curve predicted values. This chart shows that, in almost all cases, EPA's cost curves provide conservative cost estimates (erring on the high side) and are within 25 percent or less of actual project costs. In those few cases where the cost curve predictions are not within 25 percent of the actual costs, the difference can generally be attributed to the fact that the constructed cooling towers were designed for temperature approaches different than the 10 °F used for EPA's cost curves.

For the existing facility regulatory options based on flow reduction, the Agency first compared the validity of the redwood cost curve against empirical turn key costs from cooling tower projects at existing facilities. The Agency obtained four sets of total installed cooling tower costs for helper towers and expansions at existing facilities. The Agency attempted to discern if construction costs at existing facilities were inherently different from its empirically verified cost equations for new facilities. The results of this analysis showed that the median $ per gpm predictions of the redwood equation were nearly identical to those of the four existing facility projects (DCN 4522). However, the Agency determined that additional inflation of the new facility costs was necessary to compensate for the probable additional costs that would be associated with cooling system conversions. In turn, the Agency estimated a retrofit factor of 20 percent additional installed capital cost would be necessary for an average retrofit project.

As described in Chapter 4, the Agency obtained two empirical, total project costs for cooling tower conversion projects. The Agency calculated estimated project costs based on the methodology presented in Example 2 below and determined that for the case of the Palisades conversion that the Agency's methodology was very accurate. For the case of Pittsburg Unit 7, the Agency methodology for assessing conversion costs at non-nuclear plants may have understated total project capital costs (as reported by Pittsburg) by approximately 18 percent. In part, the Agency estimates that exclusion of makeup water pumps may have contributed to the difference (see Example 2). For more information on the on the cooling system example cases see Chapter 4 .

### 2.2.2 Operation and Maintenance Costs of Wet Towers

The Agency estimates that operation and maintenance costs of wet cooling tower systems for conversion projects would be the same as those developed for new, "greenfield" facilities during the 316b Phase I Rule for New Facilities. The Agency notes that recirculating pumping costs included in these operation and maintenance costs should be deducted from annual costs of cooling system conversion projects. In EPA's view, this methodology presents a realistic estimate of the actual operation and maintenance costs of cooling tower conversion projects.

Even though the Agency did not include capital costs for make-up water pumps for the cooling system conversions (see Example 2, below), the Agency includes operation and maintenance costs for delivering make-up water to the cooling towers.

Cooling towers may require replacement of equipment during the financing period that is necessary for the upkeep of the cooling tower. These costs tend to increase over the useful life of the tower and constitute an O&M expenditure that needs to be accounted for. Therefore, EPA factored these periodic equipment replacement costs into the O&M cost estimates presented herein. However, EPA has not included the replacement costs for other equipment because the life expectancy is generally expected to last over the financial life of the facility.

EPA has included the following variables in estimating O&M costs for cooling towers:

- Size of the cooling tower,
- Material from which the cooling tower is built,
- Various features that the cooling tower may include,
- Source of make-up water,
- How blowdown water is disposed, and
- Increase in maintenance costs as the tower useful life diminishes.

For example, if make-up water is obtained from a lesser quality source, additional treatment may be required to prevent biofouling in the tower.

The estimated annual O&M costs presented below are for cooling towers designed at a delta of 10 degrees. To calculate annual O&M costs for various types of cooling towers, EPA made the following assumptions:

- For small cooling towers, the annual O&M costs for chemical costs and routine preventive maintenance is estimated at 5 percent of capital costs. To account for economy of scale in these components of the O&M cost, that percentage is gradually decreased to 2 percent for the largest size cooling tower. EPA notes that, while there appear to be economies of scale for these components of O&M costs, chemical and routine preventive maintenance costs represent a small percentage of the total O&M costs and EPA does not believe there to be significant economies of scale in the total O&M costs.

- 2 percent of the tower flow is lost to evaporation and/or blowdown.

- To account for the costs of makeup water and disposal of blowdown water, EPA based the estimate on the facility using surface water sources for makeup water and disposing of blowdown water either to a pond or back to the surface water source at a combined cost of $0.5/1000 gallons.

- Based on discussions with industry representatives, the largest component of total O&M costs is the requirement for major maintenance of the tower that occurs after years of tower service, such as around the $10^{th}$ year and $20^{th}$ years of service. These major overhauls include repairs to mechanical equipment and replacement of 100 percent of fill material and eliminators.

To account for the variation in maintenance costs among cooling tower types, a scaling factor is used. Douglas Fir is the type with the greatest maintenance cost, followed by Redwood, steel, concrete, and fiberglass. For additional cooling tower features, a scaling factor was used to account for the variations in maintenance (e.g., splash fill and non-fouling film fill are the features with the lowest maintenance costs).

Using the operation cost comparison information published by Mirsky et al. (1992) and maintenance cost assumptions set out above, EPA calculated estimated costs of O&M for various types of cooling towers with and without additional features. EPA then developed cost equations from the generated cost data points. The O&M equations are shown in Charts 2-8 and 2-9 for redwood and concrete towers with various features. The following equations present the O&M costs for 10 degree F design approach redwood and concrete towers with splash fill:

$$y = -4E\text{-}6\ x^2 + 11.617\ x + 2055.2\ ,\ \text{(in 1999 \$ for with Splash Fill)}$$

where $x$ = flow in gallons per minute, valid up to 225,000 gpm.

$$y = -3E\text{-}6\ x^2 + 10.305\ x + 1837.2\ ,\ \text{(in 1999 \$ for Concrete with Splash Fill)}$$

where $x$ = flow in gallons per minute, valid up to 225,000 gpm.

Note that these cost estimates and equations are for total O&M costs. Stone and Webster (1992) presents a value for additional annual O&M costs equal to approximately 0.7 percent of the capital costs for a retrofit project. Stone and Webster's estimate is for the amount O&M costs are expected to *increase* when plants with once-through cooling systems are retrofit with cooling towers to become recirculating systems, and therefore do not represent total O&M costs of cooling tower systems.

### 2.2.3 Operation and Maintenance Costs of Baseline, Once-Through Systems

The Agency also utilizes estimates of operation and maintenance costs of once-through cooling based on a similar methodology to the costs developed for the 316b Phase I Rule for New Facilities. However, the Agency has concluded that the price of electricity used to estimate once-through system pumping costs plus ancillary operational and maintenance costs of operating the existing intake structure and other process activities is not appropriate in the context of existing facility O&M costs. The electricity price used by the Agency to reflect only the dedicated operational pumping costs of the once-through system is a realistic \$0.03/kWh. Therefore, when subtracted from the overall cooling tower operation and maintenance estimates, the once-through pumping costs would approximately represent the original pumping costs of the reused cooling water pump. If the Agency had not subtracted this element from the recurring annual costs of the cooling system conversion, the pumping costs, as compared to the baseline operating costs of the once-through system, would be miscounted. See Example 2 for a demonstration of the Agency's estimates of once-through O&M costs.

### 2.2.4 Capital Costs of Surface Condenser Refurbishments

As described in section 2.2, above, the Agency projects premature condenser refurbishments for a portion of the plants expected to incur costs of cooling tower conversions under certain regulatory options considered for this proposal. The Agency concluded that meeting a baseline standard of condenser tube material would determine which model plants would most likely upgrade condenser tube materials. In part, the Agency based this methodology based on a reference developing cost estimates for modular condenser tube replacements (Burns and

Tsou, 2001). The Agency judged that the minimum standard material would be copper-nickel alloy (of any mixture) for brackish water and stainless steel (of any type) for saline water. The Agency then consulted the 1994 UDI database (Power Statistics Unit Design Data File Part B) – the only data source the Agency is aware of with condenser tube material statistics – to determine the condenser tube material for the plants. For the units at each plant with condenser tube materials of a quality judged below that of the minimum standards mentioned above, the Agency estimates that the plant would refurbish the condenser (thereby changing out the condenser tubes) as a result of the cooling system conversion. The Agency projected that tube material for the upgrades would be stainless steel for all model plants receiving upgrade refurbishments. At some plants, EPA projects that only a portion of design intake flow serves units that would require condenser refurbishment or replacement.

As noted in the discussion above, condenser manufacturing representatives advised the Agency that plants would be motivated to upgrade condenser materials to maximize the energy efficiency of the recirculating cooling system. By upgrading the condensers for those plants utilizing less than the adjudged minimum standard (copper-nickel alloy for brackish waters and stainless steel for saline waters), the Agency determines that the turbine energy penalties derived for new, "greenfield" plants would be more applicable to the upgraded recirculating cooling systems at existing plants. See Chapter 5 of this document for the Agency's energy penalty analysis. In addition, the Agency determines that by accounting for condenser upgrades for those model plants with materials below the minimum standard that it has addressed potential condenser failures due to cooling system upgrades. See Table 2-20 for statistics on condenser materials at recirculating cooling facilities (compiled from the 1994 UDI database for all generating units in the database with cooling towers in-place).

**Table 2-20. Condenser Tubes for Units with Cooling Tower (from all Units in 1994 UDI database)**

| Percent of Cooling Tower Units with Condenser Material | |
|---|---|
| 17% | Titanium |
| 3% | Stainless Steel (any type) |
| 27% | Brass or Admir. Brass |
| 35% | Copper-Nickel Alloy (any type) |
| 12% | AL6X |
| 2% | Others |
| 5% | Unknown |

The Agency contacted condenser vendors to obtain cost estimates for refurbishing of existing condensers and for full condenser replacements. The Agency developed cost estimates (on a flow basis) for several types of condenser tube materials – copper-nickel alloy, stainless steel, and titanium. The capital cost estimates for condenser refurbishing were lower than those for full replacements, and the Agency determined that, given equal opportunity, facilities would make the economical decision to refurbish existing condensers rather than replace the waterboxes and the tube bundles. The condenser refurbishing costs developed by the Agency account for the tube materials, full labor, overhead, and potential bracing of the shell due to buoyancy changes (related to changes in tube material and, hence, densities). See Example 2 below for the condenser tube replacement and upgrade capital cost equations.

Power plants will refurbish or replace condensers on a periodic basis. Condenser vendors estimated the average useful life of condenser tubes as 20 years. In order to determine remaining useful life of the condensers at the 59 model plants, the Agency calculated a condenser replacement/refurbishing schedule based on the 20-year useful life estimate and the age of the generating units at the plants. The average useful life remaining for a condenser at the 59 model plants is approximately 9-1/2 years (in 2001). The Agency rounded this to 10 years and used this figure to represent lost operating years as a result of premature condenser refurbishments. The Agency estimates the baseline condenser material for any plant upgrading a condenser would be copper-nickel alloy. Therefore, plants upgrading condensers in order to install recirculating cooling would incur the costs of the full condenser refurbishment/upgrade to stainless steel, less the 10 years of useful life already expended, on average, in a condenser made of a lesser material (e.g., copper-nickel alloy). The economic analysis then uses these capital cost estimates in the calculation of net annualized costs. See the EBA. As explained in the EBA, the full capital cost value of the replacement is reduced to represent lost operating years of the existing condenser.

## 2.3 Recurring Annual Costs of Post-Compliance Monitoring

Existing facilities that fall within the scope of this proposed rule would be required to perform biological monitoring of impingement and entrainment, and visual or remote inspections of the cooling water intake structure and any additional technologies, on an on-going basis. Additional ambient water quality monitoring may also be required of facilities depending on the specifications of their NPDES permits. Facilities would be expected to analyze the results from their monitoring efforts and provide these results in an annual status report to the permitting authority. In addition, facilities would be required to maintain records of all submitted documents, supporting materials, and monitoring results for at least three years. (Note that the Director may require that records be kept for a longer period to coincide with the life of the NPDES permit.)

EPA expects that facility managers, biologists, biological technicians, statisticians, and clerical staff will devote time toward gathering, preparing, submitting and maintaining records of the post-compliance monitoring information that is required by the proposed rule. To develop representative profiles of each employee's relative contribution, EPA assumed burden estimates that reflect the staffing and expertise typically found in power generating plants. In doing this, EPA considered the time and qualifications necessary to complete a variety of tasks: collecting, preparing, and analyzing samples; enumerating organisms; performing statistical analyses; performing visual or remote inspections of installed technologies; compiling and submitting yearly status reports; and maintaining records of monitoring results. For each activity burden assumption, EPA selected time estimates to reflect the expected effort necessary to carry out these activities under normal conditions and reasonable labor efficiency.

The costs to the respondent facilities associated with these time commitments can be estimated by multiplying the time spent in each labor category by an appropriately loaded hourly wage rate. All base wage rates used for facility labor categories were derived from the Bureau of Labor Statistics (BLS) Occupational Handbook 2002-2003 (BLS, 2002). Additional detail on the development of cost estimates for annual post-compliance monitoring can be found in the Draft Information Collection Request for Cooling Water Intake Structures Phase II Existing Facilities Proposed Rule.

EPA estimated the annual cost of post-compliance monitoring to be approximately $62,650 for freshwater facilities (i.e., facilities withdrawing cooling water from freshwater rivers and streams; or lakes and reservoirs), and approximately $78,300 for marine facilities (i.e., facilities withdrawing cooling water from estuaries and tidal rivers; or oceans) and Great Lakes facilities.

## 2.4 One-Time Costs for Track II Demonstration Studies

Under the proposed rule, all facilities would submit a comprehensive demonstration study to characterize the source water baseline in the vicinity of the intake, characterize the operation of the intake, and confirm that the technology(ies), operational measures and restoration measures proposed and/or implemented at the intake meet the applicable performance standards. EPA developed burden and cost estimates for the comprehensive demonstration study in a manner similar to that described in section 1.4 above (i.e., by building up the estimated burdens and corresponding costs associated with the various activities being performed).

The burden estimates include: developing a proposal for collecting information to support the study; developing a description of the proposed and/or implemented technologies, operational measures and restoration measures to be evaluated and their efficacies; performing biological sampling; assessing the source waterbody; estimating the magnitude of impingement mortality and entrainment; calculating the reduction in impingement mortality and entrainment that would be achieved by the technologies and operational measures selected; demonstrating that the location, design, construction and capacity of the intake reflects the best technology available for minimizing adverse environmental impact (BTA); and reporting the results. The burden also includes developing a verification monitoring plan to verify the full-scale performance of the proposed or implemented technologies and operational measures. In addition, the burden includes performing a site-specific evaluation of the suitability of the technology(ies) and/or operational measures based on representative studies and/or site-specific technology prototype studies.

The costs to the respondent facilities associated with these time commitments can be estimated by multiplying the time spent in each labor category by an appropriately loaded hourly wage rate. Additional detail on the development of cost estimates for annual post-compliance monitoring can be found in the Draft Information Collection Request for Cooling Water Intake Structures Phase II Existing Facilities Proposed Rule.

EPA estimated the one-time costs for comprehensive demonstration studies to be approximately $827,000 for facilities withdrawing cooling water from freshwater rivers and streams, $739,000 for facilities withdrawing cooling water from lakes, $864,000 for facilities withdrawing cooling water from the Great Lakes, and $1,015,000 for facilities withdrawing cooling water from estuaries/tidal rivers or oceans.

## 2.5 Regional Cost Factors

As described in sections 2.1 and 2.2 above, the Agency developed technology-specific cost estimates for construction projects at new, “greenfield” projects on a national average basis. However, the capital construction costs can vary significantly for different locations within the United States. Therefore, to account for these regional variations, EPA adjusted the capital cost estimates for the existing model plants using state-specific cost factors, which ranged from 0.739 for South Carolina to 1.245 for Alaska. The applicable state cost factors were multiplied by the facility model cost estimates to obtain the facility location-specific capital costs used in the impact analysis.

The Agency derived the state-specific capital cost factors shown in Table 2-21 below from the “location cost factor database” in RS Means Cost Works 2001. The Agency used the weighted-average factor category for total costs (including material and installation). The RS Means database provides cost factors (by 3-digit Zip code) for numerous locations within each state. The Agency selected the median of the cost factors for all locations reported within each state as the state-specific capital cost factor.

Table 2-21. State-Specific Capital Cost Factors

| State | State Code | Median Weighted Cost Factor | State | State Code | Median Weighted Cost Factor |
|---|---|---|---|---|---|
| Alaska | AK | 1.245 | North Carolina | NC | 0.752 |
| Alabama | AL | 0.81 | North Dakota | ND | 0.827 |
| Arkansas | AR | 0.7815 | Nebraska | NE | 0.828 |

| State | State Code | Median Weighted Cost Factor | State | State Code | Median Weighted Cost Factor |
|---|---|---|---|---|---|
| Arizona | AZ | 0.864 | New Hampshire | NH | 0.913 |
| California | CA | 1.081 | New Jersey | NJ | 1.099 |
| Colorado | CO | 0.915 | New Mexico | NM | 0.912 |
| Connecticut | CT | 1.052 | Nevada | NV | 0.997 |
| DC | DC | 0.948 | New York | NY | 1.0235 |
| Delaware | DE | 1.009 | Ohio | OH | 0.955 |
| Florida | FL | 0.832 | Oklahoma | OK | 0.82 |
| Georgia | GA | 0.812 | Oregon | OR | 1.059 |
| Hawaii | HI | 1.225 | Pennsylvania | PA | 0.9765 |
| Iowa | IA | 0.886 | Rhode Island | RI | 1.039 |
| Idaho | ID | 0.932 | South Carolina | SC | 0.7385 |
| Illinois | IL | 0.994 | South Dakota | SD | 0.789 |
| Indiana | IN | 0.922 | Tennessee | TN | 0.803 |
| Kansas | KS | 0.84 | Texas | TX | 0.797 |
| Kentucky | KY | 0.847 | Utah | UT | 0.8975 |
| Louisiana | LA | 0.819 | Virginia | VA | 0.822 |
| Massachusetts | MA | 1.064 | Vermont | VT | 0.743 |
| Maryland | MD | 0.89 | Washington | WA | 1.028 |
| Maine | ME | 0.829 | Wisconsin | WI | 0.97 |
| Michigan | MI | 0.966 | West Virginia | WV | 0.943 |
| Minnesota | MN | 1.046 | Wyoming | WY | 0.787 |
| Missouri | MO | 0.925 | | | |
| Mississippi | MS | 0.7425 | Minimum | SC | 0.739 |
| Montana | MT | 0.954 | Maximum | AK | 1.245 |

## 2.6 Retrofit Cost Factor

In order to account for capital cost expenditures specific to construction at existing power plants, the Agency applies a capital cost inflation factor to the cost estimates described in sections 2.1 and 2.2 above. This capital cost inflation factor, referred to hereinafter as a "retrofit factor" accounts for activities outside the scope of the costs estimates described in sections 1.2 and 1.3. These activities relate to the "retrofit," or upgrade, of existing cooling water and intake structure systems. The Agency generally developed the cost estimates summarized in sections 2.1 through 2.2 specifically for construction projects at new, "greenfield" projects (with the exception of those for surface condenser refurbishing, which the Agency developed to inherently include retrofit activities). These projects and, therefore, the costs equations described in sections 2.1 and 2.2 generally do not include retrofit activities such as (but not limited to) branching or diversion of cooling water delivery systems, reinforcement of retrofitted conduit system connections, partial or full demolition of conduit systems and/or intake structures, additional excavation activities, temporary delays in construction schedules, expedited construction schedules, potential small land acquisitions, hiring of additional (beyond those typical for the "greenfield" cost estimates) equipment and personnel for subsurface construction, administrative and construction related safety precautions, and potential additional cooling water (recirculating or make-up) delivery needs.

The Agency estimates that a capital cost inflation factor of 20 or 30 percent applied to the costs developed for new, "greenfield" projects accounts for the retrofit activities described above. The retrofit activities represented by the factor do not relate to uncertainty of the construction project, and therefore are not considered “contingencies.” Rather, the retrofit activities are site-specific, may vary between sites, but on average, in the Agency’s view, will approach 20 percent for activity necessary to convert cooling systems and approach 30 percent for upgrading of cooling water intake structures and screens.

## 2.7 EXAMPLES OF MODEL PLANT COST ESTIMATES

### EXAMPLE 1: IMPINGEMENT AND ENTRAINMENT UPGRADE FOR ONCE-THROUGH INTAKE

Source Water: Freshwater
Steam Plant Type: Nuclear
Baseline Cooling System: Once-through
Baseline Intake Type: Trash Racks and Coarse-Mesh Screens
Baseline Design Intake Capacity: 600 million gallons per day (416,667 gpm)
Compliance Intake Type: Fine-mesh Travelling Screens with Fish Handling/Returns
Regional Capital Cost Factor: 1.00

Cooling Water Intake Technology Retrofitted Capital Cost:

- Utilized intake technology capital cost curves derived for New Facility Rule.
- Multiplied by additional retrofit cost equal to 30% of installed costs.
- Multiplied by regional capital cost factor.
- Utilized flow for sizing and construction factors as follows:

**Table EX-1 CWIS Technology Retrofit Flow Sizing and Construction Factors**

| Compliance Cooling System Type | Plant Type | Flow Used to size Cooling Water Intake Technology | Compliance Cooling Water Intake Technology | Construction Factor for Scenario |
|---|---|---|---|---|
| Cooling Tower ** | All | 50% of Once-through, Baseline Design Intake | All | None |
| Non-Cooling Tower | Non-nuclear | 100% of Once-through Baseline Design Intake | Fish Handling | None |
| Non-Cooling Tower | Non-nuclear | 100% of Once-through Baseline Design Intake | Fine Mesh Screens | 30%* |
| Non-Cooling Tower | Non-nuclear | 100% of Once-through Baseline Design Intake | Fine Mesh Screens w/ Fish Handling | 15%* |
| Non-Cooling Tower | Nuclear | 100% of Once-through Baseline Design Intake | Fish Handling | None |

**Table EX-1 CWIS Technology Retrofit Flow Sizing and Construction Factors**

| Compliance Cooling System Type | Plant Type | Flow Used to size Cooling Water Intake Technology | Compliance Cooling Water Intake Technology | Construction Factor for Scenario |
|---|---|---|---|---|
| Non-Cooling Tower | Nuclear | 100% of Once-through Baseline Design Intake | Fine Mesh Screens | 65%* |
| Non-Cooling Tower | Nuclear | 100% of Once-through Baseline Design Intake | Fine Mesh Screens w/ Fish Handling | 30%* |

* Existing facility construction factors based on average ratio of intake modification construction costs to costs derived from CWIS equations developed for New Facility projects. Thus the differences reflect differences in construction costs for nuclear and non-nuclear and differences in CWIS installation capital costs.

** For cooling sizing of cooling towers and appropriate flow for determining the costs of retrofitted cooling water systems, see Section 2.2.

Intake modification construction costs are based on the following general framework:

- An increase in screen area of 50% due to conversion from coarse-mesh to fine-mesh.
- Screen size increase will involve demolition of one side of intake and extension in that direction.
- Installation/removal of sheet piling.
- Concrete demolition of one column and one side (cost doubled for nuclear*).
- Excavation (cost doubled for nuclear*).
- Additional concrete foundation.
- Additional concrete side and back wall.
- Additional concrete column.

* EPA doubled costs to account for concerns that use of blasting and high-impact equipment may be limited at nuclear facilities.

Modification construction costs were then increased by the following cost factors:

| Item | Factor |
|---|---|
| Mobilization/Demobilization | 3 % |
| Engineering | 10 % |
| Site Work | 5 % |
| Electrical | 10 % |
| Controls | 3 % |
| Contingency | 10 % |
| Allowance | 5 % |

Fine-mesh travelling screens with fish handling/return capital cost equation:

$(5\text{ E-}11 * x^3 - 2\text{ E-}5 * x^2 + 7.1477 * x + 113116) * (1.05*1.30) *$ regional factor * construction factor
where x = appropriate flow for sizing

Total Capital Cost of Intake Structure Technology Modification for this example: <u>$5,742,300</u>
(addition of fine-mesh travelling screens with fish handling/return to the existing intake).

Total Capital Cost of Intake Upgrade: $5,742,300.

Cooling Water Intake Technology O&M Costs:

Based on outreach with industry representatives, EPA estimated annual O&M cost as a percentage of total capital cost (that is, those costs developed for new facility projects, not including retrofit factors). The O&M cost factor ranges between 8 percent of total capital cost for the smallest size traveling screens with and without fish handling equipment and 5 percent for the largest traveling screen since O&M costs do not increase proportionately with screen size. The screen O&M costs are based on the size of the screen, which are based on the initial sizing flow. For this example, the Agency uses the sizing flow of full, baseline once-through flow.

O&M Equation for Fine-mesh Travelling Screens with Fish Handling/Return:
$-3\text{ E-}13 * x^3 – 4\text{ E-}8 * x^2 + 0.2081 * x + 11485$

Cooling Water Intake Technology O&M Costs for This Example: $69,548

Total Annual O&M Costs for this Example: $69,548

## EXAMPLE 2: COOLING SYSTEM CONVERSION

Source Water: Estuary / Tidal River
Steam Plant Type: Fossil
Baseline Cooling System: Once-through
Baseline Intake Type: Trash Racks and Coarse-Mesh Screens
Baseline Design Intake Capacity: 600 million gallons per day (416,667 gpm)
Converted Cooling System: Mechanical-Draft Wet Cooling Towers
Compliance Intake Type: Fine-mesh Travelling Screens with Fish Handling/Returns
Reduced Intake Capacity: 33,333 gpm (416,667 gpm * 0.08)
Regional Capital Cost Factor: 1.08

Recirculating Wet Cooling Tower Cost Development:

Cooling Tower Material of Construction: Redwood
Number of Cooling Tower Units: 2
Cooling Flow for Each Tower Unit: 208,334 gpm

Basic Redwood Tower with Splash Fill Capital Cost Equation:

$n * (-5\text{E-}5 * x^2 + 70.271 * x + 25393) * \text{regional factor},$
where $x$ = cooling flow per unit
$n$ = number of cooling units

Items included in the installed tower capital cost equation:

- Wet tower, furnished & erected
    includes internal tower piping, risers, and valves
    includes splash fill
    includes fans and motors
    includes electrical service and housing
- Site preparation, clearing, grading
- Excavation for basins and piping
- Circulating water piping, valves, and fittings to and from condenser
- Access roads
- Full circulating pumps and housing
- Installed concrete basins, sumps, and footings
- Electrical wiring, controls, and transformers
- Blowdown-water treatment facility
- Acceptance testing
- Installation

Factors included in the installed tower capital cost equation (i.e., these factors inflate the direct capital costs):

- Construction management, mobilization and demobilization
- Design engineering and architectural fees
- Contractor overhead and profit
- Turnkey Fee
- Contingencies

Additional Cooling Tower Retrofit Scaling Factor: 20 percent.
Regional Capital Cost Factor: 1.08

Total Capital Cost of Installed Cooling Tower (2 unit tower system): $44,550,000 (new facility project cost) + $8,910,000 (retrofit cost factor) = <u>$53,550,000</u>

<u>Intake and Discharge Piping Modification Capital Costs:</u>

Pipe modification costs are based on the following assumptions:[5]

- Piping material and installation cost is $12 per in-diameter per ft-length.

[5] The Agency excluded makeup water pump costs from its derived equations for cooling system conversions. In doing so, the Agency attempted to compensate for the situations where existing pumps can be reused in the converted recirculating system, as was the case for the Jefferies Steam Plant conversion (see Chapter 4 for futher discussion of cooling tower conversion example cases). However, the Agency recognized that the probability of existing circulating water pumps being reused for retrofitted tower systems was low. Therefore, because the Agency was able to confirm the reuse of existing intake structures for three of the example cases, the Agency considered the cost of the makeup pump to offset the possible savings of pump reuse such as the Jefferies plant to be appropriate. The Agency estimates that the installed cost of intake pumps, such as for the model plant cost example above, would be a very small fraction of the total cost of the installed cooling tower system (less than 0.25 percent). For the final rule's analyses, the Agency will consider the costs of new intake pumps at a portion, or all cooling system conversions.

- Additional retrofit cost equal to 30% of material and installation.
- Note: EPA inadvertently excluded excavation, backfill, and other civil costs from the intake piping modifications. This could represent a significant cost increase. The Agency intends to rectify this error for the final rule's analysis.
- Additional cost factors as follows:

| Item | Factor |
|---|---|
| Mobilization/Demobilization | 3% |
| Engineering | 10% |
| Site Work | 5% |
| Controls | 3% |
| Contingency | 10% |
| Allowance | 5 % |

- Pipe characteristics as follows:

**Table EX-2 Pipe Characteristics for Intake Piping Modifications for Cooling Conversions**

| Compliance Intake Flow (gpm) | Pipe Diameter (in) | Pipe Velocity (fps) | Pipe Length (ft) |
|---|---|---|---|
| 1,000 | 8 | 6.4 | 2,000 |
| 5,000 | 16 | 8.0 | 2,000 |
| 10,000 | 20 | 10 | 2,000 |
| 50,000 | 42 | 12 | 3,000 |
| 100,000 | 60 | 11 | 4,000 |
| 350,000 | 60 (3 pipes) | 13 | 4,000 |

Cost equation (incorporating retrofit factor and all other factors) derived is as follows:

(-0.00002*Flow^2 + 48.801*Flow + 350292) * regional factor

Total Capital Cost of Intake/Discharge Piping Modification for this example: $1,955,000

Cooling Water Intake Technology Retrofit Capital Cost:

- Utilized intake technology capital cost curves derived for New Facility Rule.
- Multiplied by additional retrofit cost equal to 30% of installed costs.
- Multiplied by regional capital cost factor.
- Utilized flow for sizing and construction factors as described in Table EX-1 above:

Fine-mesh travelling screens with fish handling/return capital cost equation:

$(5\text{ E-}11 * x^3 - 2\text{ E-}5 * x^2 + 7.1477 * x + 113116) * (1.05*1.30)$ * regional factor * construction factor
where x = appropriate flow for sizing (which is 50 % of baseline, once-through flow for this example)

Total Capital Cost of Intake Structure Technology Modification for this example: $1,748,800 (this includes addition of fine mesh travelling screens with fish handling/return to the existing intake).

Total Capital Cost of Cooling System Conversion and Intake Upgrade: $57,414,400.

Condenser Upgrade Capital Costs:

EPA estimates that some condensers would require upgrades premature to the end of their useful lives due to the cooling system conversion. For this example case, the condenser baseline tube material is Copper/Nickel Alloy. The Agency determined that the tubes would be upgraded to 304 Stainless Steel for a cooling tower using brackish cooling water. This upgrade would occur when the existing condenser had 10 years of useful life remaining. Therefore, EPA developed cost estimates for the tube upgrade and the tube replacement.

The Capital Cost equation for CuNi replacement is as follows:

Number of Cooling Tower Units * (18.046 * Unit Cooling Flow – 13134) * Regional Factor.

- Accounts for cost of materials
- Accounts for vibration/stability analysis
- Accounts for labor, overhead, etc.
- EPA utilizes a 1.58 factor for safety at nuclear plants
- Replacement tubing includes non-corroding internal tubing liner
- Does not include an additional retrofit or allowance, due to the fact that the cost estimates forming the basis of the curves were for actual tube replacement projects.

Capital Cost of Existing Material Condenser Tube Replacement: $8,029,400

Capital Cost of Condenser Tube Upgrade: $8,774,600

The economic analysis calculates the net capital cost to the facility for the premature replacement of the condenser tube sheets. The analysis accounts for the upgraded material and deducts the useful life of the replacement. See the Economic and Benefits Analysis for more information.

Operation and Maintenance Costs of Baseline Intake Pumping (once-through):

- Pumping head estimated at 50 ft for all systems.
- Pump and motor efficiency estimated at 70 percent.
- Annual hours of operation estimated at 7860 (i.e., 90 percent of 8760).
- Energy cost estimated at $0.03/KWh. This value is set near the average wholesale cost of electricity. To be conservative, this estimation of the unit energy cost is intended to account for the pumping electricity costs and does not account for such O&M costs as pump maintenance.

  Baseline Intake Pumping Annual Cost Equation: - (50 * Flow * 8.33 * 0.746 * 7860 * 0.03) / (33,000 * 0.7)

  Baseline Intake Annual Pumping Cost in this Example: $1,321,500

Wet Cooling Tower Operation and Maintenance:

- Includes periodic equipment replacement and maintenance costs (i.e., $10^{th}$ and $20^{th}$ year overhauls).

- Includes pumping and fanning O&M requirements.
- Includes blowdown-water treatment and disposal.
- Accounts for increase in equipment replacement costs as tower useful life diminishes.
- Includes chemical addition.
- Does not include turbine efficiency penalty, which is factored into the economic analysis through lost revenue.

Redwood Wet Tower O&M Equation: $n * (-4E\text{-}6 * x^2 + 11.617 * x + 2055.2)$
Where $x$ = cooling flow per unit
$n$ = number of cooling units

Wet Cooling Tower O&M Cost Estimate for this Example: <u>$4,497,300</u>

<u>Intake Pumping O&M Costs:</u>

Developed in a manner very similar to the once-through, baseline intake pumping costs. However, the compliance intake flow is used in place of the baseline, once-through flow.

Wet Tower Compliance Intake Pumping O&M Cost Estimate for this Example: <u>$105,700</u>

<u>Cooling Water Intake Technology O&M Costs:</u>

Based on outreach with industry representatives, EPA estimated annual O&M cost as a percentage of total capital cost (that is, those costs developed for new facility projects, not including retrofit factors). The O&M cost factor ranges between 8 percent of total capital cost for the smallest size traveling screens with and without fish handling equipment and 5 percent for the largest traveling screen since O&M costs do not increase proportionately with screen size. The screen O&M costs are based on the size of the screen, which are based on the initial sizing flow. For this example, the Agency uses the sizing flow of ½ of the baseline once-through flow.

O&M Equation for Fine-mesh Travelling Screens with Fish Handling/Return:
$-3\,E\text{-}13 * x^3 - 4\,E\text{-}8 * x^2 + 0.2081 * x + 11485$

Cooling Water Intake Technology O&M Costs for This Example: <u>$50,390</u>

Total Annual O&M Costs for this Example: <u>$3,331,900</u>

## 2.9 Repowering Facilities and Model Plant Costs

Under this proposed rule certain forms of repowering could be undertaken by an existing power generating facility that uses a cooling water intake structure and it would remain subject to regulation as a Phase II existing facility. For example, the following scenarios would be existing facilities under the proposed rule:

- An existing power generating facility undergoes a modification of its process short of total replacement of the process and concurrently increases the design capacity of its existing cooling water intake structures;

- An existing power generating facility builds a new process for purposes of the same industrial operation and concurrently increases the design capacity of its existing cooling water intake structures;

- An existing power generating facility completely rebuilds its process but uses the existing cooling water intake structure with no increase in design capacity.

Thus, in most situations, repowering an existing power generating facility would be addressed under this proposed rule.

As discussed in Section III.B of the preamble, the section 316(b) Survey acquired technological and economic information from facilities for the years 1998 and 1999. With this information, the Agency established a subset of facilities potentially subject to this rule. Since 1999, some existing facilities have proposed and/or enacted changes to their facilities in the form of repowering that could potentially affect the applicability of this proposal or a facility's compliance costs. The Agency therefore conducted research into repowering facilities for the section 316(b) existing facility rule and any information available on proposed changes to their cooling water intake structures. The Agency used two separate databases to assemble available information for the repowering facilities: RDI's NEWGen Database, November 2001 version and the Section 316(b) Survey.

In January 2000, EPA conducted a survey of the technological and economic characteristics of 961 steam-electric generating plants. Only the detailed questionnaire, filled out by 283 utility plants and 50 nonutility plants, contains information on planned changes to the facilities' cooling systems (Part 2, Section E). Of the respondents to the detailed questionnaire, only six facilities (three utility plants and three nonutility plants) indicated that their future plans would lead to changes in the operation of their cooling water intake structures

The NEWGen database is a compilation of detailed information on new electric generating capacity proposed over the next several years. The database differentiates between proposed capacity at new (greenfield) facilities and additions/modifications to existing facilities. To identify repowering facilities of interest, the Agency screened the 1,530 facilities in the NEWGen database with respect to the following criteria: facility status, country, and steam electric additions. The Agency then identified 124 NEWGen facilities as potential repowering facilities.

Because the NEWGen database provides more information on repowering than the section 316(b) survey, the Agency used it as the starting point for the analysis of repowering facilities. Of the 124 NEWGen facilities identified as repowering facilities, 85 responded to the section 316(b) survey. Of these 85 facilities, 65 are in-scope and 20 are out of scope of this proposal. For each of the 65 in scope facilities, the NEWGen database provided an estimation of the type and extent of the capacity additions. The Agency found that 36 of the 65 facilities would be combined-cycle facilities after the repowering changes. Of these, 34 facilities are projected to decrease their cooling water intake after repowering (through the conversion from a simple steam cycle to a combined-cycle plant). The other 31 facilities within the scope of the rule would increase their cooling water intake. The Agency examined the characteristics of these facilities projected to undergo repowering and determined the waterbody type from which they withdraw cooling water. The results of this analysis are presented in Table 2-22.

Table 2-22 - In-scope Existing Facilities Projected to Enact Repowering Changes

| Waterbody Type | Repowering Facilities Projected to Increase Cooling Water Withdrawals | Repowering Facilities Projected to Decrease or Maintain Cooling Water Withdrawals |
|---|---|---|
| Ocean | N/A | N/A |
| Estuary/Tidal River | 3 | 17 |
| Freshwater River/Stream | 14 | 10 |
| Freshwater Lake/Reservoir | 10 | 1 |
| Great Lake | 0 | 1 |

Of the 65 in scope facilities identified as repowering facilities in the NEWGen database, 24 received the detailed questionnaire, which requested information about planned cooling water intake structures and changes to capacity. Nineteen of these 24 facilities are utilities and the remaining five are nonutilities. The Agency analyzed the section 316(b) detailed questionnaire data for these 24 facilities to identify facilities that indicated planned modifications to their cooling systems which will change the capacity of intake water collected for the plant and the estimated cost to comply with today's proposal. Four such facilities were identified, two utilities and two nonutilities. Both utilities responded that the planned modifications will decrease their cooling water intake capacity and that they do not have any planned cooling water intake structures that will directly withdraw cooling water from surface water. The two nonutilities, on the other hand, indicated that the planned modifications will increase their cooling water intake capacity and that they do have planned cooling water intake structures that will directly withdraw cooling water from surface water.

Using the NEWGen and section 316(b) detailed questionnaire information on repowering facilities, the Agency examined the extent to which planned and/or enacted repowering changes would effect cooling water withdrawals and, therefore, the potential costs of compliance with this proposal. Because the Agency developed a cost estimating methodology that primarily utilizes design intake flow as the independent variable, the Agency examined the extent to which compliance costs would change if the repowering data summarized above were incorporated into the cost analysis of this rule. The Agency determined that projected compliance costs for facilities withdrawing from estuaries could be lower after incorporating the repowering changes. The primary reason for this is the fact that the majority of estuary repowering facilities would change from a steam cycle to a combined-cycle, thereby maintaining or decreasing their cooling water withdrawals (note that a combined-cycle facility generally will withdraw one-third of the cooling water of a comparably sized full-steam facility). Therefore, the portion of compliance costs for regulatory options that included flow reduction requirements or technologies could significantly decrease if the Agency incorporated repowering changes into the analysis. As shown in Table 2-22 the majority of facilities projected to increase cooling water withdrawals due to the repowering changes use freshwater sources. In turn, the compliance costs for these facilities would increase if the Agency incorporated repowering for this proposal.

## 2.9 Capacity Utilization Rate Cut-off

The Agency is proposing standards for reducing impingement mortality but not entrainment when a facility operates at a capacity utilization rate of less than 15 percent over the course of several years (see § 125.94 (b)(2) of the proposed rule). Capacity utilization rate means the ratio between the average annual net generation of the facility (in MWh) and the total net capability of the facility (in MW) multiplied by the number of available hours during a year. The average annual generation is to be measured over a five year period (if available) of representative operating conditions. Incorporation of capacity utilization into the level of control was found to be the most economically practicable given these facilities' reduced operating levels. Fifteen percent capacity utilization corresponds to facility operation for roughly 55 days in a year (that is, less than two months). The Agency refers to this differentiation between facilities based on their operating time as a capacity utilization cut-off. Facilities operating at capacity utilization rates of less than 15 percent are generally facilities of significant age, including the oldest facilities within the scope of the rule. Frequently, entities will refer to these facilities as peaker plants, though the definition extends to a broader range of facilities. These peaker plants are less efficient and more costly to operate than other facilities. Therefore, operating companies generally utilize them only when demand is highest and, therefore, economic conditions are favorable. Because these facilities operate only a fraction of the time compared to other facilities, such as base-load plants, the peaking plants achieve sizable flow reductions over their maximum design annual intake flows. The lower the intake flow at a site, the lesser the potential for entraining of organisms. Therefore, the concept of an entrainment reduction requirement for such facilities does not appear necessary. Additionally, the plants typically operate during two specific periods: the extreme winter and the extreme summer demand periods. Each of these periods can, in some cases, coincide with periods of abundant aquatic concentrations and/or sensitive spawning events. However, it is generally accepted that peak winter and summer periods will not be the most crucial for aquatic organism communities on a national basis.

Based on an analysis of data collected through the detailed industry questionnaire and the short technical questionnaire, EPA believes that today's proposed rule would apply to 539 existing steam electric power generating facilities. Of these, 53 facilities operate at less than 15 percent capacity utilization and would potentially only comply with impingement controls, with 34 of these estimated to actually require such controls. (The remaining 19 facilities have existing impingement controls).

Of the facilities exceeding the capacity utilization cut-off, the median and average capacity utilization is 50 percent. As a general rule, steam plants operate cyclically between 100 percent load and standby. In turn, the intake flow rate of a typical steam plant cycles between flows approaching the full design rate and standby (that is, near-zero intake flow). Facilities operating with an average capacity utilization of 50 percent would generally withdraw more than three times as much water over the course of time than a facility with a capacity utilization of less than 15. Therefore, the capacity utilization cut-off coincides with an approximate flow reduction, and hence entrainment reduction, of roughly 70 percent as compared to the average facility above the cut-off. This level of reduction is within the range of performance standards for entrainment reduction. Were the Agency to establish the cut-off at less than 20 percent capacity utilization, an additional 18 facilities would be subject to the reduced requirements and the comparable flow reduction would be roughly 60 percent. The operating period would extend to approximately 75 days (that is, 2.5 months) for the hypothetical 20 percent cut-off. Were the Agency to establish the cut-off at less than 25 percent capacity, 108 of the 539 facilities would be subject to the reduced standards, and the comparable entrainment reduction would be roughly 54 percent. For a hypothetical 25 percent capacity utilization cut-off, the operating period would extend to approximately three months.

The median age of generating units with capacity utilization factors less than 15 percent is 48 years in 2002. The median age of generating units with capacity utilization factors of less than 25 percent and equal to or greater than 15 percent is 43 years. The age of generating units shows a continued trend upwards as capacity utilization rate increases. This trend agrees with the theory that existing peaking plants generally are aged facilities only dispatched when economic conditions are favorable and/or demand is highest.

The Agency examined the cooling water use of all plants for trends associated with or related to capacity utilization. As the analysis of unit age described above shows, most plants with low capacity utilization rates are very old. These plants generally utilize once-through cooling systems. For some plants, not all generating units may be available or capable of operating during extended periods, and the plant may staggered operation of generating units may be employed. However, as discussed above, the Agency believes that these aged units generally operate at or near peak capacity when they are dispatched. Therefore, the intake pumps will operate at near design intake capacity when functioning. Because a peaker plant will only operate for limited times during the year, its overall use of water (that is, the average annual intake) would be significantly below its design maximum intake rate. The Agency calculated a ratio of actual annual intake (for 1998) to maximum-design annual intake for the plants within the scope of this rule and compared this to capacity utilization. Though the data shows a significant degree of scatter, the Agency concludes that the data plotted in Figure 2-1 (actual-to-design intake ratio versus capacity utilization rate for all model plants within scope of this proposed rule) shows that generally, the lower the capacity utilization of a plant, the lower the intake flow as a percent of the maximum design intake capability.

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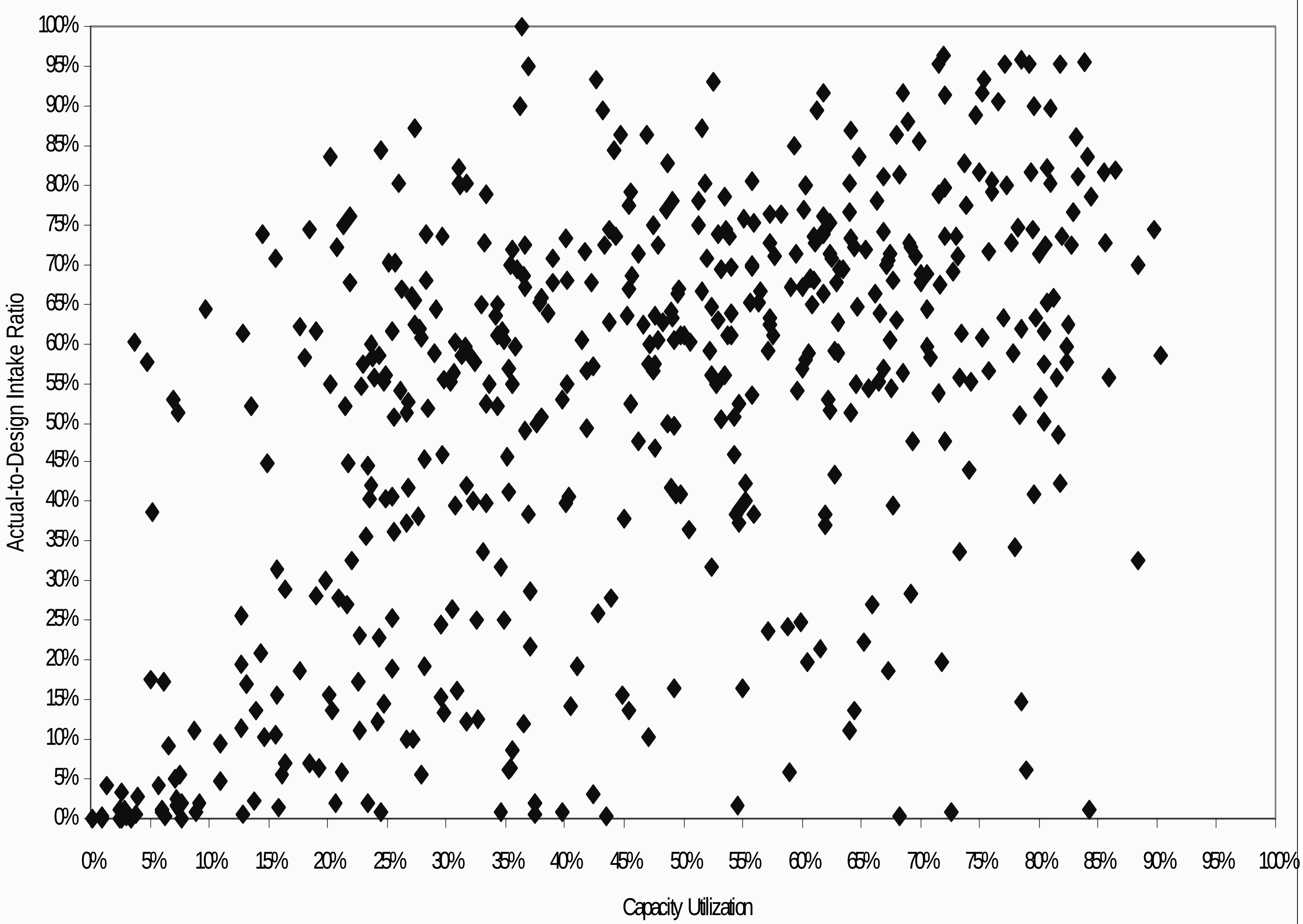
Figure 2-1. Actual-to-Design Intake versus Capacity Utilization for All Model Plants

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**List of Cost Curves and Equations in Appendix B**